Auckland East Coast Estuarine Monitoring Programme:
Report on data collected up until October 2015

February 2017 Technical Report 2017/003

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Cover photograph of Whangateau Harbour by Jay Farnworth

Auckland East Coast Estuarine Monitoring Programme: Report on data collected up until October 2015

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Executive summary

The significant threat of increased terrestrial sediment runoff into estuaries and coastal zones as a result of land use changes was recognised by the National Institute of Water and Atmospheric Research (NIWA) and the Auckland Regional Council (ARC) in the 1990s. Starting with Okura in 2000, the ARC began ecological monitoring in order to better assess the impacts of sediment loads on the health of valued estuarine resources. The abundances of nine macrofauna taxa, macrofaunal community characteristics and bed sediment characteristics are now monitored at four sites in each of seven east coast estuaries (Puhoi, Waiwera, Orewa, Mangemangeroa, Turanga, Waikopua and Whangateau), with 10 sites sampled in Okura due to the developments proposed within its catchment and immediate shoreline.

The estuarine monitoring programme provides important information on the health of these estuaries which has been used as evidence in state of the environment reporting, report cards and the development of the Auckland Unitary Plan. This report documents the degree to which each estuary may be affected by terrestrial sediment inputs as well as their present status.

Decreases in sediment mud content have been observed at many sites, however, increases in the total percent of very fine particles (sized <124 µm) have also been observed. All monitored sites in Waikopua showed increases in very fine particle content; three of the four sites in Mangemangeroa and Turanga and 8 of the ten sites in Okura showed increases in very fine particle content. The other estuaries either showed change at no sites (Whangateau) or only one or two sites (Puhoi (1), Waiwera (1) and Orewa (2)).

In Okura, a trend consistent with sedimentation was detected at every site and changes in community composition consistent with increasing mud content were detected at nearly half the sites. For those estuaries with only four sites monitored, in Turanga more than one trend consistent with increased sedimentation was detected at all sites; in Orewa and Mangemangeroa more than one trend consistent with increased sedimentation was detected at three of the four sites. Turanga, Waiwera, Mangemangeroa and Whangateau also exhibited trends consistent with sedimentation in community level indicators (CAPmud and/or number of taxa) at three of the four sites. Overall, this suggests that there are concerning changes at Okura in terms of the number of sites exhibiting trends consistent with sedimentation. Changes observed in Turanga, Whangateau, Waiwera and Mangemangeroa are also of concern. The estuary showing the fewest changes of concern is Puhoi.

Generally the estuaries are in moderate to good health. Whangateau and Orewa were rated “moderate’ to “very healthy” with respect to mud content, and all sites in Okura and Whangateau were rated high in terms of functionality. Puhoi, Orewa and Whangateau were rated as the healthiest in terms of metal contamination. A combined health score comprised of three benthic health indices (TBI index, BHM_{mud} score and BHM_{metal} score) indicated that sites within these estuaries varied from poor to extremely good. Waiwera, Turanga, Mangemangeroa and Waikopua estuaries stand out as having at least one site with a low combined health rating. All four of these estuaries contain a site rated “poor” and neither Turanga, Mangemangeroa nor Waikopua had sites rated as “extremely good”. Okura had no sites rated below moderate health with most being “good”.

All of the monitored estuaries remain at risk from sediment derived from rural activities, land clearance and forestry, and currently the monitoring is detecting some trends consistent with increased sediment in these estuaries. At present, the degree of monitoring reflects Auckland Council's knowledge of proposed developments. We suggest that the monitoring continues in its present form unless Auckland Council knows of proposed developments that would occur in specific locations within estuaries other than Okura. We do not suggest dropping any of the estuaries completely, or removing any more sites, as temporal dynamics in the indicators recorded at estuaries and sites with primarily natural variation are extremely useful in providing natural baselines.

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1.0 Background

1.1 Rationale and initial programme design

Planning for growth in the Auckland region has for some time suggested that the estuaries on the fringes of the metropolitan area are prime candidates for residential expansion and development. Early in the 1990's, the significant threat of increased terrestrial sediment runoff into estuaries and coastal zones as a result of this development was recognised by NIWA and the then Auckland Regional Council (ARC). Initially it was thought that muddy areas (e.g., tidal creeks and upper estuary areas) would be less affected than sandy areas, but a number of small-scale experimental studies, co-funded by FRST (Foundation for Research, Science and Technology) and ARC, found that all areas were potentially at risk (Norkko et al. 2002). Around the east coast of the Auckland Region, ecological responses were observed as a result of quite small experimental applications of terrestrial sediment onto the seafloor and into the water column. These responses ranged from changes in the feeding behaviour and health of individual species to complete eradication of whole macrofaunal communities (Ellis et al. 2002, Hewitt & Pilditch 2004, Lohrer et al. 2004, Norkko et al. 2006, Hewitt & Norkko 2007). To inform planning and decision-making, the ARC melded catchment modelling of likely sediment runoff under various development scenarios with estuarine sediment transport models and results of experimental manipulations on ecology.

Ecological experimental manipulations can only be conducted at small scales, and a number of problems arise in trying to scale up from a one-off, small-scale experiment to potentially large-scale and cumulative impacts (Thrush et al. 1999, Hewitt et al. 2007). A weight of evidence approach has been used to infer broader-scale effects by comparing the taxa shown to be sensitive in the experiments with those demonstrating relationships with sediment mud content or sediment accumulation rates from large-scale surveys (Lundquist et al. 2003, Gibbs & Hewitt 2004, Thrush et al. 2004, Anderson et al. 2007). As stronger evidence is often required in a court of law and monitoring is also required to determine the long term effectiveness of planning decisions, in 2000 the ARC began monitoring in Okura Estuary (conducted by UniServices). The intention was to capture any changes in the ecology of the estuary associated with planned development, across three phases: pre-development, development and post-development.

In August 2002, four other estuaries were added to the monitoring programme (Puhoi, Waiwera, Orewa and Mangemangeroa). Mangemangeroa was added as the urbanisation beginning to occur around its catchment was planned to intensify over time. The other three were added in order to place any potential changes through time in the other estuaries within a broader regional context. However, Mangemangeroa is spatially separated from the others (lying to the south of Auckland City and discharging into the Whitford Embayment). To enable useful comparisons to be made for this estuary, Turanga and Waikopua (also from the Whitford Embayment) were added to the regional monitoring programme in August 2004.

In 2009, the collection and analysis of data shifted from UniServices to NIWA. Although there was a potential for this change to result in step changes in the data, this was assessed in 2010 and no effects were observed. NIWA also shifted the emphasis of the analyses to 'within' estuaries, which allowed the monitoring to be bought into line with many of the other benthic ecological monitoring programmes run by the Auckland Council. That is, after five years of consistent monitoring, a temporally nested monitoring design was introduced, where the number of sites monitored continuously in each harbour was reduced to seven with the remaining three sites monitored on a rotational basis (Hewitt & Thrush 2007). The effect of this reduction in sites was assessed in 2010 (Hewitt & Simpson 2012) and biyearly after that, No effect on the ability of the data to allow detection of changes over time in an estuary was observed. Also in 2009, a further estuary (Whangateau) was added to the monitoring programme, following a habitat and baseline monitoring survey in 2009/2010 (Townsend et al. 2010), which was triggered by the potential for development around the estuary. The report on the monitoring programme which analysed data collected to the end of 2011 (Hewitt & Simpson 2012) confirmed that Whangateau could be analysed in conjunction with the rest of the estuaries with the sediment and macrofaunal characteristics of the chosen sites fitting well into the range of the seven other presently sampled estuaries. In November 2010, monthly monitoring of environmental variables (volume and grain size of sediment caught in the sediment traps and height of the bed) was discontinued. This monitoring comprised a significant portion of the costs but the data had proven unreliable due to a number of issues. The available resolution of the bed height measurements relative to expected sedimentation rates was of particular concern. Monitoring sediment accumulation rates is an area that needs further study to develop appropriate, reliable methods (Hewitt et al. 2014a; Townsend & Lohrer 2015).

In 2011, for the first time, the estuarine monitoring programme was amalgamated with contaminant sampling conducted by Auckland Council throughout the region. Contaminant and macrofaunal data for these areas was analysed using the Benthic Health Models related to sediment mud content and heavy metal contamination (Hewitt & Simpson 2012). The data have also been analysed for the Traits-Based Index (TBI) and was included in a report summarising the state of monitoring sites around the region (Hewitt et al. 2012). Collection of chlorophyll *a* data began in 2012 and in October 2014 sampling was reduced to four core sites per estuaries except for Okura where all 10 sites are sampled. The sites cover upper, mid and lower estuary, and correspond to the contaminant monitoring sites and locations of sediment plates. Note that sediment plates present at other sampling locations are still measured.

The design of the monitoring centred on the three phases of development that differed in their timing of occurrence between estuaries. Ten monitoring sites were located along the length of each estuary, with the assumption that sites furthest up the estuary were most likely to be impacted by terrestrial sedimentation. Along the estuary, sites were further stratified into those occurring in depositional zones versus erosional zones. The ongoing monitoring and comparisons over time within and among estuaries was designed to detect long-term effects on macrofaunal community structure driven by chronic increases in both the turbidity and in the proportion of fine muddy sediments in the estuary.

From 2000 – 2014, event based monitoring, on top of regular monitoring, was carried out to determine whether individual sediment depositional events resulted in changes to the benthic communities (see Hewitt et al. 2014a). This monitoring concluded in October 2014, and results are not reported here.

1.2 Questions this report is seeking to address

This report focusses on a number of questions:

- Are there changes occurring which are indicative of increased sedimentation?
- How similar are the sediment characteristics of the estuaries?
- What is the overall health status of the estuaries, as measured by the Benthic Health Models and the TBI?

2.0 Long-term monitoring methods

Here we present the general sampling methodologies of the long-term monitoring programme. Methods specific to a particular section are discussed within that section.

2.1 Estuaries and sites

Eight small east coast estuaries are monitored: Puhoi, Waiwera, Orewa, Okura, Mangemangeroa, Turanga, Waikopua and Whangateau (Figure 2-1). These estuaries have been sampled for varying lengths of time: Okura from April 2000; Puhoi, Waiwera, Orewa, and Mangemangeroa from August 2002; and Turanga and Waikopua from August 2004; and Whangateau from October 2009.

Initially 10 sites were sampled within each estuary (with the exception of Whangateau) with site 1 being closest to and site 10 being furthest from the mouth of the estuary (see section 3.0 for placement of the sites). Sites are located at mid-tide elevation and have dimensions of 50 m (parallel to the waterline) x 25 m (perpendicular to the waterline). Placement was chosen to cover a range of sediment types (mud to coarse sand).

In August 2009, seven of the sites across the gradient in each estuary were monitored (Core sites) with the remaining sites sampled on a rotational basis over a five year period (Table 2-1). Since April 2014, all ten sites in Okura have been monitored and in October 2014 the number of core sites in the other estuaries was reduced to four sites (Table 2- 1). The four sites were chosen from the existing core sites retaining those where sediment chemistry had been monitored within each estuary and are representative of the communities and mud content found along each estuary. Given this, the remainder of the report will focus only on the reduced set of monitored sites.

Table 2-1: Sites monitored from October 2014 to present.

Estuary	Sites
Okura	All 10
Whangateau	1,4,5,7
Puhoi	1,4,7,9
Waiwera	1,3,6,8
Orewa	1,3,4,8
Mangemangeroa	3,5,6,9
Turanga	1,4,7,8
Waikopua	1,3,6,9

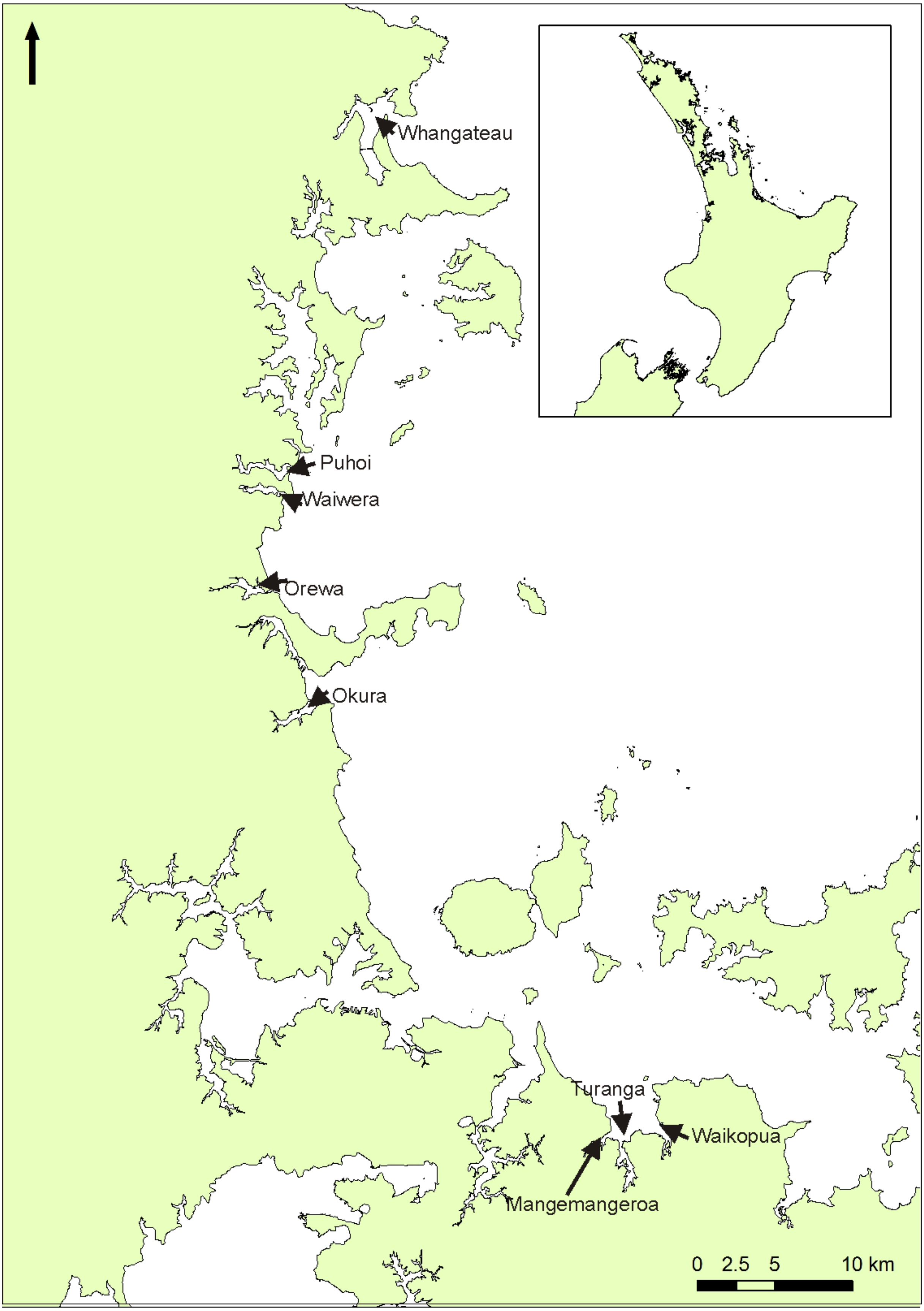

Figure 2-1: Location of the eight monitored estuaries.

2.2 Macrofauna

2.2.1 Collection and processing

Initially, sampling occurred twice (after rain, and after a dry period) within each of two three-month blocks (winter/spring: August–October and summer/autumn: February–April), yielding four sampling times per year. In 2007, this was altered, the dry sampling was maintained (although the time period for sampling was standardised to the months of October and April where possible). The event based rainfall sampling was changed to being triggered by rainfall events in excess of 60, 57.5 and 50.6 mm over a 24 hr period recorded at gauging stations in Orewa, Okura and Mangemangeroa respectively. Only estuaries where the trigger occurred were sampled and sampling occurred within seven to ten days of the trigger event. From 2011 to 2014 sampling occurred in October and April when no rain events have been recorded in the prior two weeks. The rainfall over the 24 hour, two week and three week periods prior to sampling was recorded and used in the analysis to help explain any variability not related to seasonality. In Oct 2014 event based rainfall sampling was dropped from the programme, with sampling now occurring bi-annually, once in April and once in October (when weather and tidal condition permitted).

At each site, six replicate macrofaunal cores (130 mm in diameter x 150 mm deep) are taken from random positions at each site, excluding the area within 5 m of a core location for the previous 6 months. Cores are sieved on a 0.5 mm mesh and the material retained preserved in 70% isopropyl alcohol with 0.01% rose bengal. Later the macrofauna are identified to the lowest practical taxonomic level (usually species) and counted but due to the lower resolution of UniServices data (prior to 2009) some species are grouped into families (i.e., Nereididae). Anderson et al. (2007) noted that the level of taxonomic resolution has increased markedly through time, and that community-level analyses should only use data from August 2002 onwards. Throughout the analysis in this report the level of taxonomic resolution reported in Appendix 5 (Anderson et al. 2007) has been used.

Individuals from three bivalve species (the cockle *Austrovenus stutchburyi*, the wedge shell *Macomona liliana* and the pipi *Paphies australis*) are placed into size classes (small <5 mm, medium 5-15 mm, and large >15 mm) to allow some assessment of changes in the population structure of these large and long-lived animals.

2.2.2 Community indices and selected species

Two community indices are calculated and analysed in this programme that we expect to be sensitive to increased terrestrial sediment inputs: number of taxa; and community composition related to mud content. Average number of taxa per sample is expected to decrease with increased sedimentation rates (Lundquist et al. 2003). Community composition related to mud content is obtained from a canonical analysis of principle coordinates (CAP; Anderson & Willis 2003), based on Bray-Curtis similarities of square-root transformed data, and related to the percentage mud sediment content across the seven original estuaries. The CAP estuary model data integrate temporal variation in macrofaunal abundances and percentage mud from a restricted time period (averaged dry sampled values from spring 2004 to autumn 2007 for each of the 70 sites, Anderson 2008). Macrofaunal community composition on new occasions and in the additional Whangateau Estuary, are mapped onto the canonical axis of the mud gradient model using the ‘add samples’ option available in Primer V6 providing a value that is related to mud content (henceforth called CAPmud score).

Although derived using a CAP procedure to extract community composition related to mud content, this CAPmud score differs from the scores obtained using the Auckland Council BHMmud used to define estuarine community health around the Auckland Region. The BHMmud model is constructed from a more spatially extensive set of data, allowing a regional assessment of health and health scores that can be directly compared with other sites around the region. Conversely, the CAPmud score, created from a specific set of estuaries with time averaged data, allows change over time related to increased mud content for those specific estuaries to be assessed more precisely. The regionally comparable health indices are discussed in section 2.5 (methods) and 3.3 (results).

The analysis in this report also focusses on nine taxa for which responses to sediment mud content are known (Anderson 2008). Five taxa (*Paphies australis, Colurostylis spp., Anthopleura aureoradiata, Waitangi brevirostris* and *Aonides trifida* (called *oxycephala* in early reports) were predicted to strongly prefer low mud content and three taxa (crabs - a combination of abundances of *Halicarcinus*, *Austrohelice* and *Hemiplax* species, Nereididae polychaetes and Corophidae amphipods) were predicted to prefer high mud content. The results were similar to those found by Thrush et al. (2003, 2005) using maximum density models and thus are likely to be robust, although Anderson (2008) reports a stronger positive relationship between % mud content and Nereididae abundance, and a stronger negative relationship with % mud content for *Austrovenus* and *Macomona* than the relationships in Thrush et al. (2003 and 2005).

Analyses were also conducted on the abundances in three different size classes (small <5 mm, medium 5-15 mm, and large >15 mm) of the measured bivalves (*Austrovenus*, *Macomona* and *Paphies*).

2.3 Sediment

As well as macrofaunal sampling, ambient sediment is sampled to determine changes in sediment grain size. Initially, ambient sediment samples were obtained adjacent to each faunal core using a 38 mm diameter x 15 cm deep corer. This, however, diluted any changes in sediment characteristics by the bulk and depth of the material collected in the core. Since August 2004, sampling changed to using a 2 cm diameter core to a depth of approximately 2 cm.

Six sediment cores from a single site are combined into a single sample which is frozen until grain size analysis can occur. Prior to grain size analysis, organic matter is removed using 9% hydrogen peroxide until effervescing ceased. The sample is then wet-sieved on a stack of sieves (2000, 500, 250, 125 and 63 µm). Each fraction is dried to a constant weight at 60°C. Sediment % weight is then expressed for shell (>2000 µm), coarse sand (500 - 1999 µm), medium sand (250–499 µm), fine sand (125–249 µm), very fine sand (63–124 µm) and mud (< 63 µm). Due to differences in sediment sampling methods between NIWA and UniServices (depth of sediment sampled, sizes of sieves used) only data from August 2004 onwards are used for subsequent analyses.

Sampling in Whangateau initially used the same sampling protocol for ecological monitoring programmes conducted in Manukau, Mahurangi and Central and Upper Waitematā Harbours. In these programmes, very fine sand and fine sand were not separated, and the mud component was separated by pipette analysis into % sand (4 – 63 µm) and % clay (<3.9 µm). However, from 2011, Whangateau samples have been analysed into six fractions as per the other sites within the Estuarine Monitoring Programme.

Beginning in the autumn of 2006, organic content of the sediment was calculated using a loss on digestion method with 9% hydrogen peroxide. However, since spring 2009 organic content has been determined using the same method used in other Auckland Council monitoring programmes. Approximately 5 g of sediment is placed in a dry, pre-weighed tray. The sample is then dried at 60^{o}C until a constant weight is achieved (as above). The sample is then combusted for 5.5 h at 400^{o}C and then reweighed and the percentage loss on ignition is calculated.

Finally, since September 2012 additional sediment has been collected for analysis of sediment chlorophyll *a* content. As per the grain size sample, six sediment cores (2 cm diameter and 2 cm depth) from a single site, within the vicinity of macrofaunal cores, are combined into a single sample are pooled and stored frozen in the dark. Within a month of collection the samples are freeze dried and analysed. Chlorophyll *a* is extracted by boiling this freeze dried sediment in 90% ethanol, and the extract processed using a spectrophotometer. An acidification step is used to separate degradation products from chlorophyll *a* (Sartory 1982).

2.4 Trends over time

Temporal changes in sediment characteristics, community indices, abundances of selected taxa and bivalve size classes, within the eight estuaries, (since 2004) were determined using the following procedure:

- Visual assessments of plots over time were used to determine whether (a) step changes (see *Aonides* plot in Figure 4-2 for an example of a step change) or (b) multi-year cycles occurred.
- If a step change was indicated, analysis was conducted using a t-test.
- Otherwise, a regression with time was run, using log transformations to include monotonic non-linear responses. Polynomial non-linear responses were not investigated as we were only interested in continuous long-term trends. Two further steps were taken in the analysis:
- Where a statistically significant trend was observed ($p < 0.05$) residuals were examined for any temporal structure that indicated the presence of cyclic patterns in the data that might drive the detection of trends (Fox, 1991). Investigation of residuals will become increasingly important with time as the ability to detect small trends increases with the number of sampling times. Figure 2-2 shows a time series of 19 points. After only 10 points have been collected a statistically significant trend is detected. With a further 6 points the trend is still statistically significant, but a clear pattern in the residuals has emerged, rather than a decreasing trend there is a cyclic pattern. In our trend analysis we would classify this as a possible trend only.

- Initially, rainfall statistics generated from the preceding 3 weeks were included as co-variables, however, these did not prove to be important predictors, probably as all sampling had been conducted after low rainfall.

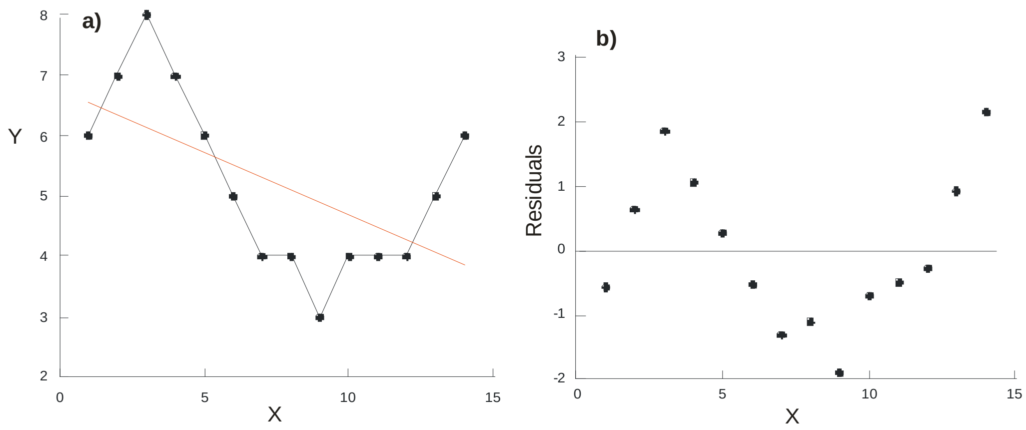

Figure 2-2: Example plot of a statistically significant trend (p = 0.0259), which is likely to be a cyclic pattern. A strong pattern can be seen in both (a) the original time series and (b) the residuals over time. Due to the cyclic pattern, this would only be described as possible trend in this report and not included in the summaries.

2.5 State of the Environment Indicators

2.5.1 Benthic Health Models

The original benthic health model (BHMmetals) was developed to determine the health of macrofaunal communities relative to storm-water contaminants. The model is based on a multivariate analysis of the variation in macrofaunal community composition related to total sediment copper, lead and zinc concentrations, extracted from the 500 µm fraction of the sediment (Anderson et al. 2006).

In 2010-2011, another model was developed, this time to determine health relative to sediment mud content (BHMmud, Hewitt & Ellis 2011). At the time of the development of this model it was determined that while there was some crossover between community compositions found in response to high mud and high contaminants, the two effects could still be separated.

Both models are based on the community composition observed at 84 intertidal sites in the Auckland Region between 2002 and 2005. The sites are within tidal creeks, estuaries or harbours, but do not include exposed beaches. They cover a range of contaminant concentrations and mud content. The models use Canonical Analysis of Principal Coordinates (CAP, Anderson & Willis 2003) of square root transformed Bray-Curtis dissimilarities to extract variation related to a single environmental variable and produce a score of community composition related to that variable. For the metal model, the concentrations of the three metals have been used in a Principle Component Analysis to create a single axis (PC1) that explains >90% of the variability in contaminant differences between the sites. For the mud model, the percentage mud content of sediment at the time of sampling is used.

The macrofaunal community composition of sites and sampling times not in the models are compared to model data (using the “add new samples” routine in CAP, PermANOVA addon, Primer E). The samples are then allotted to five different groups related to health; ≤ 0.2 “extremely good”; 0.2 < value < 0.4 “good”; 0.4 < value < 0.6 “moderate”; 0.6 < value < 0.8 “poor” and ≥ 0.8 “unhealthy” (Table 2-2).

2.5.2 Traits-Based Index

Organisms can be categorised according to characteristics (traits) that are likely to reflect ecosystem function (i.e., their feeding mode, degree of mobility, position in the sediment column, body size, body shape, capacity to create tubes/pits/mounds, etc.). During 2010 and 2011, an index based on these biological traits was created (van Houte-Howes & Lohrer 2010) and improved (Lohrer & Rodil 2011). The index is based on seven broad trait categories (living position, sediment topography feature created, direction of sediment particle movement, degree of mobility, feeding behaviour, body size, body shape and body hardness). Specifically the richness of taxa exhibiting seven particular traits: living in the top 2 cm of sediment, having an erect structure or tube, moving sediment around within the top 2 cm, being sedentary or only moving within a fixed tube, being a suspension feeder, being of medium size, or being worm shaped. Values of this index range from 0-1, with values close to 0 indicating low levels of functional redundancy and highly degraded sites. Values closest to 1 indicate high levels of functional redundancy, which is indicative of healthy areas (high functional redundancy tends to increase the inherent resistance and resilience in the face of environmental changes (Hewitt et al. 2012)). The index has been refined over the last couple of years (Hewitt et al. 2012) with the SUMmax parameter modified to allow the metric to be applied to a wider range of sites and those sampled with differing numbers of replicates (Lohrer & Rodil 2011).

2.5.3 Combined Indices

Hewitt et al. (2012) recommended the use of the three indices above (TBI index, BHMmud score and BHMmetals score) to provide a complementary assessment of health. Average health values are determined for each site in the following way:

- If the BHMmud score is ≤ -0.12, the site is allocated to Mud group 1, and the combined Health score is calculated as the average BHMmetals and BHMmud group values. The TBI is not used in the combined score in this case, as it does not work well when mud content is extremely low (Hewitt et al. 2012).
- If the BHMmetals score is ≥0.0234, the site is allocated to group 4 or 5, and the combined Health score is equal to the TBI group value. At this level of contaminants, the TBI score itself fully reflects health.
- Otherwise, Health is the average of the BHMmetals, BHMmud and TBI group values.

Health scores are then translated as ≤ 0.2 “extremely good”; 0.2 < value < 0.4 “good”; 0.4 < value < 0.6 “moderate”; 0.6 < value < 0.8 “poor” and ≥ 0.8 “unhealthy with low resilience”. It is important to recognise that the health scores are from particular sites within each estuary, and do not necessarily represent the health status of each estuary as a whole. There may be locations in each estuary that are significantly healthier, or less healthy, than the monitored sites.

Table 2-2: Conversion of BHMmetals and BHMmud scores into health groups (1 is most healthy). Cut off point is equal or less than. These groups are then converted (along with TBI scores) into values of similar scale (0 to 1) that run in the same direction (higher values indicating more degraded conditions), to facilitate their combination into overall health scores.

Group	BHMmetals			BHMmud			TBI		
	Cut off	Value	Class	Cut off	Value	Class	Cut	Value	Class
1	-0.1640	0.2	Extremely good	-0.12	0.2	Extremely good	0.4	0.33	Good
2	-0.0667	0.4	Good	-0.05	0.4	Good	0.3	0.67	Intermediate
3	0.0234	0.6	Moderate	0.02	0.6	Moderate		1.00	Poor
4	0.1000	0.8	Poor	0.10	0.8	Poor			
5		1.0	Unhealthy		1.0	Unhealthy			

3.0 Present status of the estuaries

3.1 Sediments

3.1.1 Organic matter

Percent organic matter varied little across the estuaries with values greater than 5% being rare (Figure 3-1). In general sites furthest from the mouth of the estuaries had higher organic matter than those closer, with the exception of Waiwera site 1 which is located in a small embayment at the mouth of the estuary (Figure 3-1).

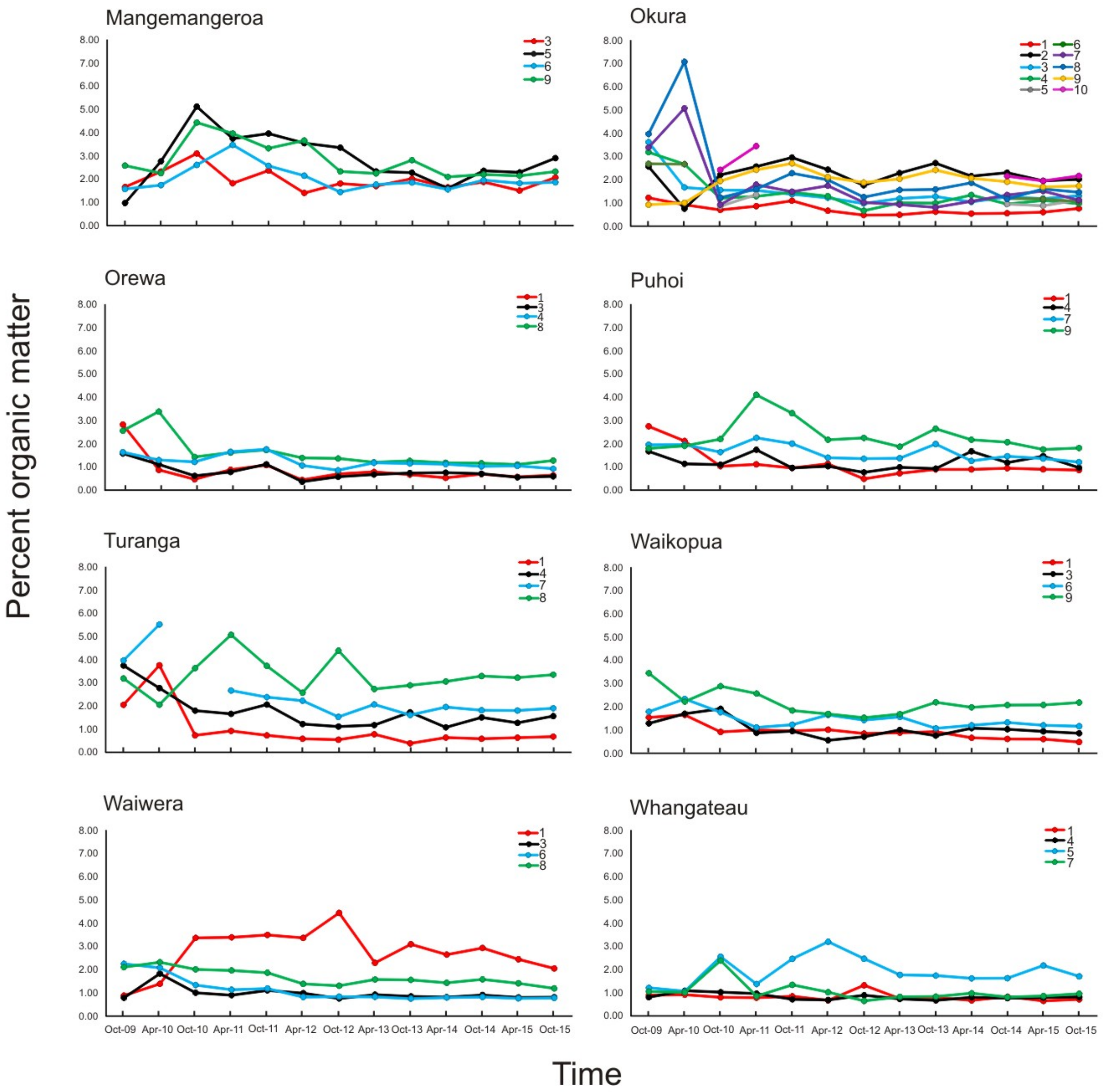

Figure 3-1: Organic sediment content at monitored sites since Oct 2009 to Oct 2015. Note that the data for % Organic matter at site 7 in Turanga for October 2010 is missing.

3.1.2 Chlorophyll *a*

The estuaries separate into three groups based on chlorophyll *a* content of the sediment: Whangateau, Orewa, Waiwera, Waikopua and Puhoi (low at all sites; annual average between 5 – 9 $\mu g.g^{-1}$); Turanga and Mangemangeroa (high at all sites; annual average between 13 - 18 $\mu g.g^{-1}$); and Okura (variable; sites annual averages range between 4.5 - 23.5$\mu g.g^{-1}$). Within each estuary the variation over time at each site is generally low (standard deviation <3 $\mu g.g^{-1}$), with the exception of Okura and Turanga (standard deviation of 4 and 6 $\mu g.g^{-1}$, respectively). The data record for chlorophyll *a* is not long enough for trend analysis, however from visual inspection there are no obvious trends in chlorophyll *a* content along the length of the estuaries (Figure 3-2).

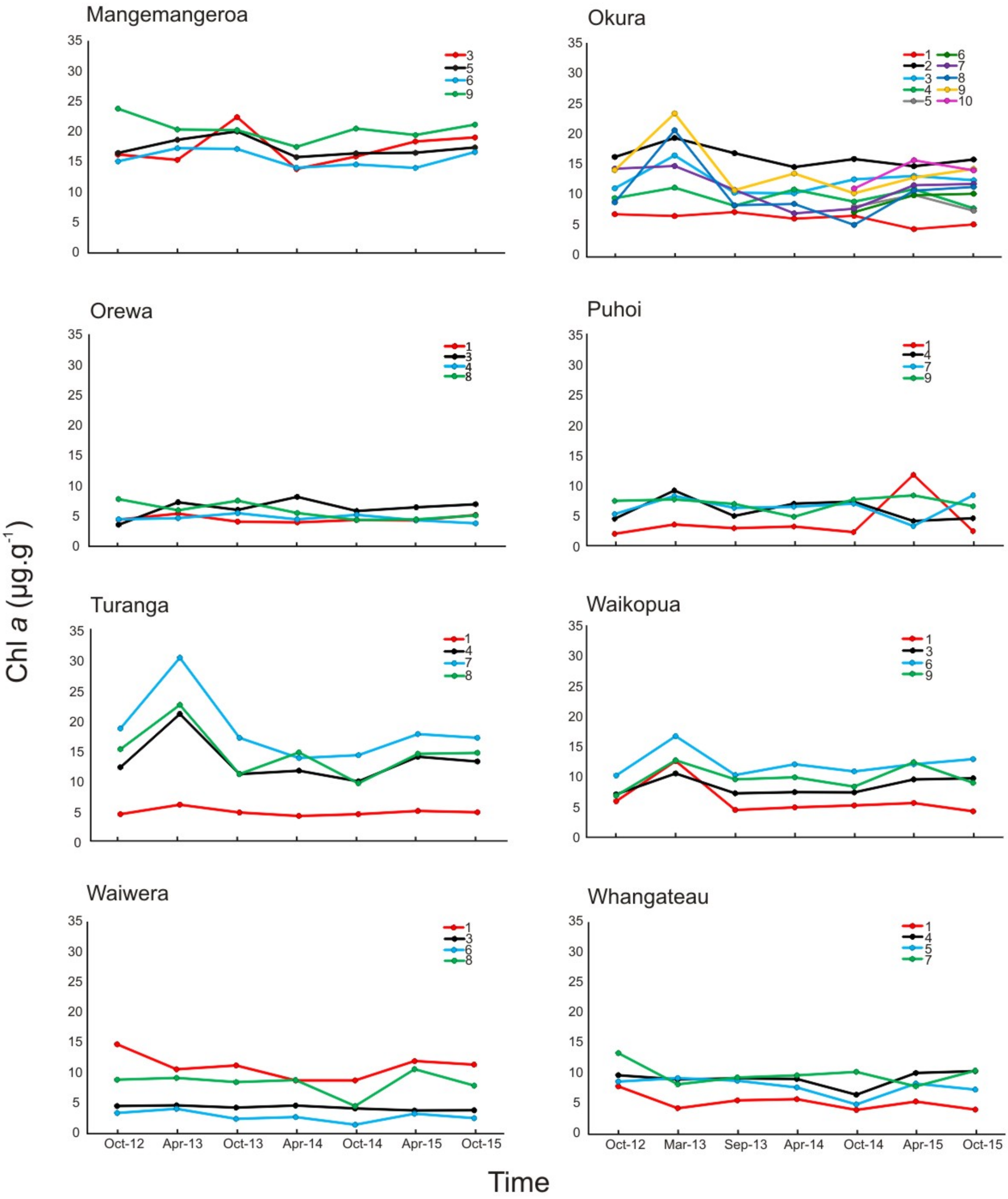

Figure 3-2: Sediment chlorophyll *a* content ($\mu g.g^{-1}$) at monitored sites in Mangemangeroa, Okura Orewa, Puhoi, Turanga, Waikopua, Waiwera and Whangateau (from left to right) , since Oct 2012 to Oct 2015.

3.1.3 Grain size

Estuaries overlap strongly in grain size characteristics (Figure 3-3). For all estuaries, sites furthest up the estuaries generally have higher average mud and very fine sand content, while those closest to the mouth have more fine sands. The sediment composition at Waiwera is mostly composed of medium to fine sands while Turanga is largely composed of very fine sands. Okura is an example of an estuary that shows a clear split, from fine sediment in the lower reaches and very fine in the upper reaches. Mangemangeroa site 3 is the only site with a large proportion of coarse sand and gravel (Figure 3-3).

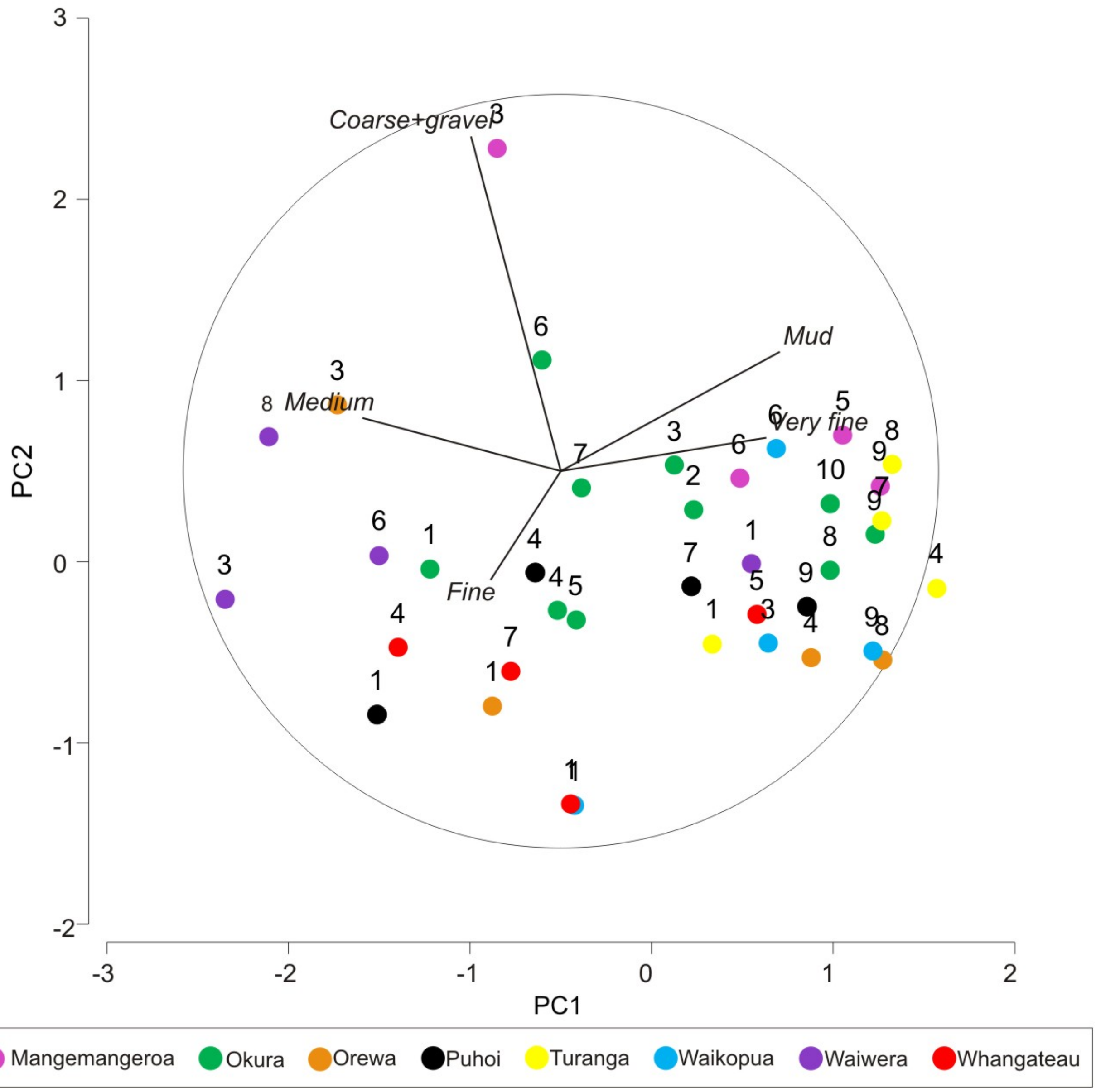

Figure 3-3: Principal component analysis showing similarities between estuaries in grain size characteristics, based on averages since spring 2009. Points closest together are more similar than those further apart.

3.2 Macrofauna communities

Ordination of the full macrofaunal community composition data (Figure 3-4) shows that the estuaries are, in general, not distinct from each other however some of the estuaries are more similar to one another than other estuaries. For example Puhoi, Orewa and Waiwera tend to group closer to each other than with the other estuaries (Figure 3-4).

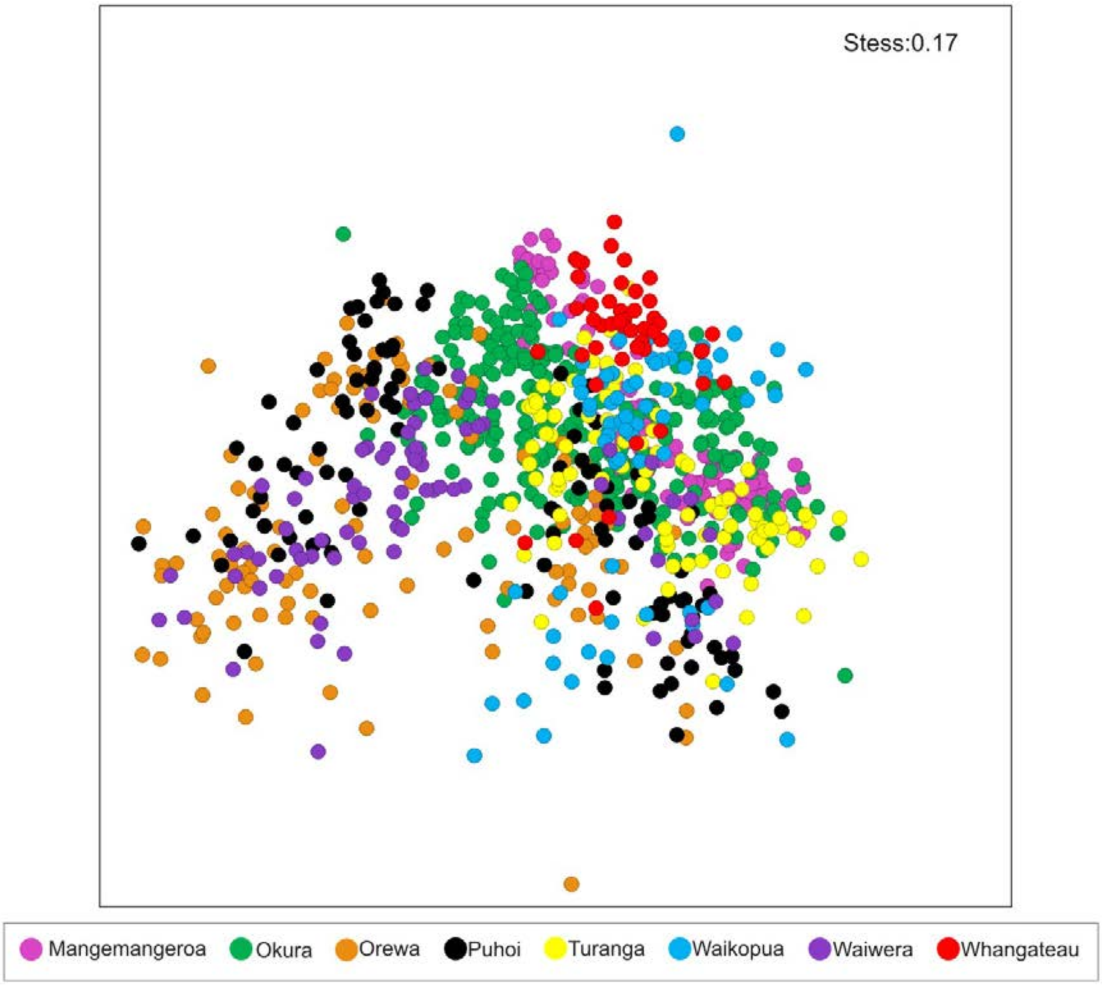

Figure 3-4: Non-metric multidimensional ordination of average abundances of all taxa at each monitored sites within eight estuaries from spring 2004 to spring 2015. Sites that are closest together on the plot are most similar in community composition.

3.3 Health status of the estuaries

3.3.1 Benthic Health Models

The benthic health models are an indication of macrofaunal community health relative to stormwater contaminants (BHMmetals) and sediment (BHMmud). Scores range approximately from 0.20 to -0.20 with lower values indicative of better health. These continuous scores can also be converted into categories of health (1-5) using cut-off values (Anderson et al. 2006).

Benthic health model scores have been calculated from spring sampling times in 2009 – 2015 at the monitoring sites from each estuary (four in all estuaries, ten in Okura where all sites were sampled). In each estuary, three sites have been validated in 2011 by collecting heavy metal and mud content information and comparing the model predicted values with the observed values. However, the benthic health models do not require environmental data for new sites to be allocated health scores. We have reported on health for both validated and non-validated sites (see Table 3-1), as we are reasonably confident about the scoring for all estuaries with the exception of Whangateau and Waikopua where the degree of fit between the BHM model predictions of heavy metals and mud content suggest that the degree of health may be underestimated (Hewitt & Simpson 2012).

With only six years, and one point per year, examining temporal patterns would not be valid. However, standard errors provide a good assessment of within-site variability over time. Most sites in most estuaries had low variability for the scores related to metal contamination (BHMmetals average score, Table 3-1, see Table 3-2 for the most recent scores), with scores related to mud content (BHMmud score) generally slightly less variable. Okura and Orewa had the most sites with highest temporal variability in BHMmetals and BHMmud scores, however it is important to remember that Okura sites 5, 6 and 10 have only had benthic health scores calculated on three sampling occasions. None of the temporal variability is sufficient to move a score across a health category, unless the sites are very close to the boundary. Sites that are close to boundaries are: Mangemangeroa (site 9), Waikopua (sites 6 and 9), and Waiwera (site 6) for metals; and Okura (sites 1, 3, 4, 7 and 9), Orewa (site 8), Puhoi (sites 4 and 7), Turanga (sites 1 and 4), Waikopua (site 6), Waiwera (site 6) and Whangateau (site 7) for mud content. Care needs to be taken in assessing changes over time at these sites.

Based on the metal scores, Orewa had the healthiest sites, varying between extremely good to good health. All the other estuaries exhibited a larger range of scores, with sites varying from extremely good to moderate health. No estuary had sites that scored as poor or unhealthy.

Based on the mud scores, there were four groups of estuaries. Okura, Turanga and Waiwera ranged from poor to extremely good. Mangemangeroa, Puhoi and Waikopua ranged from poor to good health. Whangateau ranged from moderate to good health, while Orewa from moderate to extremely good health.

Table 3-1: Average and standard error (SE) of scores over time (spring 2009 to 2015) for each site. See Table Appendix 7-117.4 for individual scores. The colouration for BHMmetal and BHMmud means extremely good (blue); good (green); moderate (yellow); poor (orange) and unhealthy (red). For TBI the colouration means good (blue); intermediate (yellow) and poor (red) levels of functional redundancy/resilience. Sites marked with a * are non-validated sites, underlined Okura sites are core sites.

Estuary	Site	BHMmetal		BHMmud		TBI	
		Mean	SE	Mean	SE	Mean	SE
Mangemangeroa	3	-0.098	0.004	-0.077	0.004	0.620	0.025
	5	-0.024	0.009	0.042	0.005	0.386	0.020
	6*	-0.044	0.011	0.013	0.010	0.472	0.022
	9	-0.008	0.009	0.063	0.006	0.336	0.019
Okura	1	-0.183	0.004	-0.145	0.005	0.469	0.020
	2*	-0.061	0.007	-0.008	0.008	0.598	0.047
	3*	-0.164	0.006	-0.103	0.008	0.517	0.028
	4*	-0.161	0.006	-0.128	0.004	0.606	0.044
	5*	-0.147	0.012	-0.096	0.006	0.570	0.034
	6*	-0.121	0.012	-0.109	0.012	0.694	0.054
	7	-0.162	0.008	-0.122	0.007	0.512	0.031
	8*	-0.116	0.015	-0.062	0.015	0.486	0.033
	9	-0.042	0.015	0.014	0.013	0.431	0.022
	10*	-0.016	0.012	0.062	0.004	0.500	0.051
Orewa	1	-0.159	0.015	-0.100	0.015	0.244	0.013
	3*	-0.178	0.010	-0.125	0.005	0.380	0.037
	4	-0.162	0.015	-0.122	0.016	0.388	0.031
	8	-0.082	0.017	-0.021	0.017	0.314	0.047
Puhoi	1	-0.177	0.006	-0.118	0.006	0.373	0.025
	4	-0.158	0.006	-0.119	0.005	0.457	0.020
	7*	-0.098	0.015	-0.053	0.015	0.434	0.041
	9	-0.016	0.008	0.043	0.009	0.358	0.022
Turanga	1*	-0.149	0.005	-0.128	0.004	0.424	0.041
	4	-0.023	0.009	0.032	0.009	0.365	0.040
	7	-0.075	0.006	-0.016	0.004	0.461	0.043
	8	0.005	0.007	0.072	0.007	0.307	0.021

Estuary	Site	BHMmetal		BHMmud		TBI	
		Mean	SE	Mean	SE	Mean	SE
Waikopua	1	-0.106	0.009	-0.053	0.008	0.695	0.041
	3	-0.085	0.012	-0.083	0.013	0.530	0.028
	6*	-0.079	0.009	-0.052	0.009	0.494	0.039
	9	0.006	0.013	0.043	0.005	0.326	0.046
Waiwera	1	-0.016	0.012	0.032	0.014	0.374	0.041
	3	-0.154	0.005	-0.098	0.006	0.256	0.034
	6*	-0.170	0.006	-0.130	0.005	0.451	0.029
	8	-0.156	0.005	-0.116	0.006	0.462	0.036
Whangateau	1	-0.072	0.006	-0.070	0.003	0.453	0.016
	4	-0.085	0.009	-0.092	0.003	0.590	0.020
	5	-0.055	0.005	-0.042	0.006	0.484	0.020
	7*	-0.081	0.005	-0.079	0.005	0.666	0.016

3.3.2 Traits-Based Index

The Traits Based Index (TBI) is a measure of a site's functional redundancy, centred on the richness of taxa in seven biological trait categories. Values close to 0 indicate low levels of functional redundancy and are indicative of highly degraded sites, whereas values closer to 1 indicate healthier sites.

TBI scores were more variable over time than the BHMmetal and BHMmud scores (Table 3-2), with sites in Okura, Orewa, Waikopua and Turanga exhibiting high variability. Only Orewa, Turanga, Waiwera and Waikopua contained some sites with low functional redundancy.

3.3.3 Combined Indices

The TBI, BHMmetals and BHMmud can be combined into a single index of health. For the combined index, lower scores (≤0.2) are better and an indication of good health, whereas scores approaching 1 are indicative of unhealthy areas with low resilience.

Combining these indices into the single health score (Table 3-2) resulted in sites in estuaries varying from poor to extremely good (Figure 3-5). Okura, Orewa and Whangateau have no sites rated poor whereas Puhoi, Turanga Mangemangeroa, Waiwera and Waikopua estuaries all have at least one site with a poor health rating. Mangemangeroa, Waikopua, Whangateau or Turanga had no sites rated as "extremely good".

Table 3-2: Scores and groups for the three indices and the combined health score for 2015 data.

	BHM_{metal} score	BHM_{mud} score	TBI score	BHM_{metal} group	BHM_{mud} group	TBI group	Health Score
Mangemangeroa							
3	-0.11	-0.08	0.69	2	2	1	0.38
5	-0.03	0.04	0.49	3	4	1	0.58
6	0.00	0.05	0.50	3	4	1	0.58
9	0.02	0.06	0.38	3	4	2	0.69
Okura							
1	-0.19	-0.12	0.45	1	1	1	0.20
2	-0.04	-0.01	0.48	3	3	1	0.51
3	-0.16	-0.12	0.51	2	2	1	0.38
4	-0.15	-0.12	0.78	2	2	1	0.38
5	-0.13	-0.10	0.50	2	2	1	0.38
6	-0.10	-0.09	0.70	2	2	1	0.38
7	-0.15	-0.12	0.52	2	1	1	0.30
8	-0.07	-0.02	0.47	2	3	1	0.44
9	-0.01	0.02	0.42	3	3	1	0.51
10	0.00	0.06	0.54	3	4	1	0.58
Orewa							
1	-0.17	-0.10	0.26	1	2	3	0.53
3	-0.21	-0.14	0.39	1	1	2	0.20
4	-0.21	-0.17	0.47	1	1	1	0.20
8	-0.10	-0.02	0.34	2	3	2	0.56
Puhoi							
1	-0.15	-0.09	0.30	2	2	3	0.60
4	-0.17	-0.12	0.46	1	1	1	0.20
7	-0.13	-0.06	0.33	2	2	2	0.49
9	-0.03	0.03	0.40	3	4	1	0.58
Turanga							
1	-0.15	-0.12	0.44	2	1	1	0.30
4	-0.01	0.06	0.28	3	4	3	0.80
7	-0.09	-0.03	0.65	2	3	1	0.44
8	0.02	0.09	0.27	4	4	3	1.00

	BHM_{metal} score	BHM_{mud} score	TBI score	BHM_{metal} group	BHM_{mud} group	TBI group	Health Score
Waikopua							
1	-0.12	-0.08	0.61	2	2	1	0.38
3	-0.09	-0.08	0.49	2	2	1	0.38
6	-0.07	-0.06	0.44	3	2	1	0.44
9	0.02	0.06	0.26	4	4	3	1.00
Waiwera							
1	0.00	0.06	0.34	3	4	2	0.69
3	-0.14	-0.08	0.24	2	2	3	0.60
6	-0.16	-0.12	0.44	2	1	1	0.30
8	-0.17	-0.13	0.52	1	1	1	0.20
Whangateau							
1	-0.08	-0.08	0.48	2	2	1	0.38
4	-0.11	-0.08	0.65	2	2	1	0.38
5	-0.05	-0.03	0.53	3	3	1	0.51
7	-0.08	-0.06	0.69	2	2	1	0.38

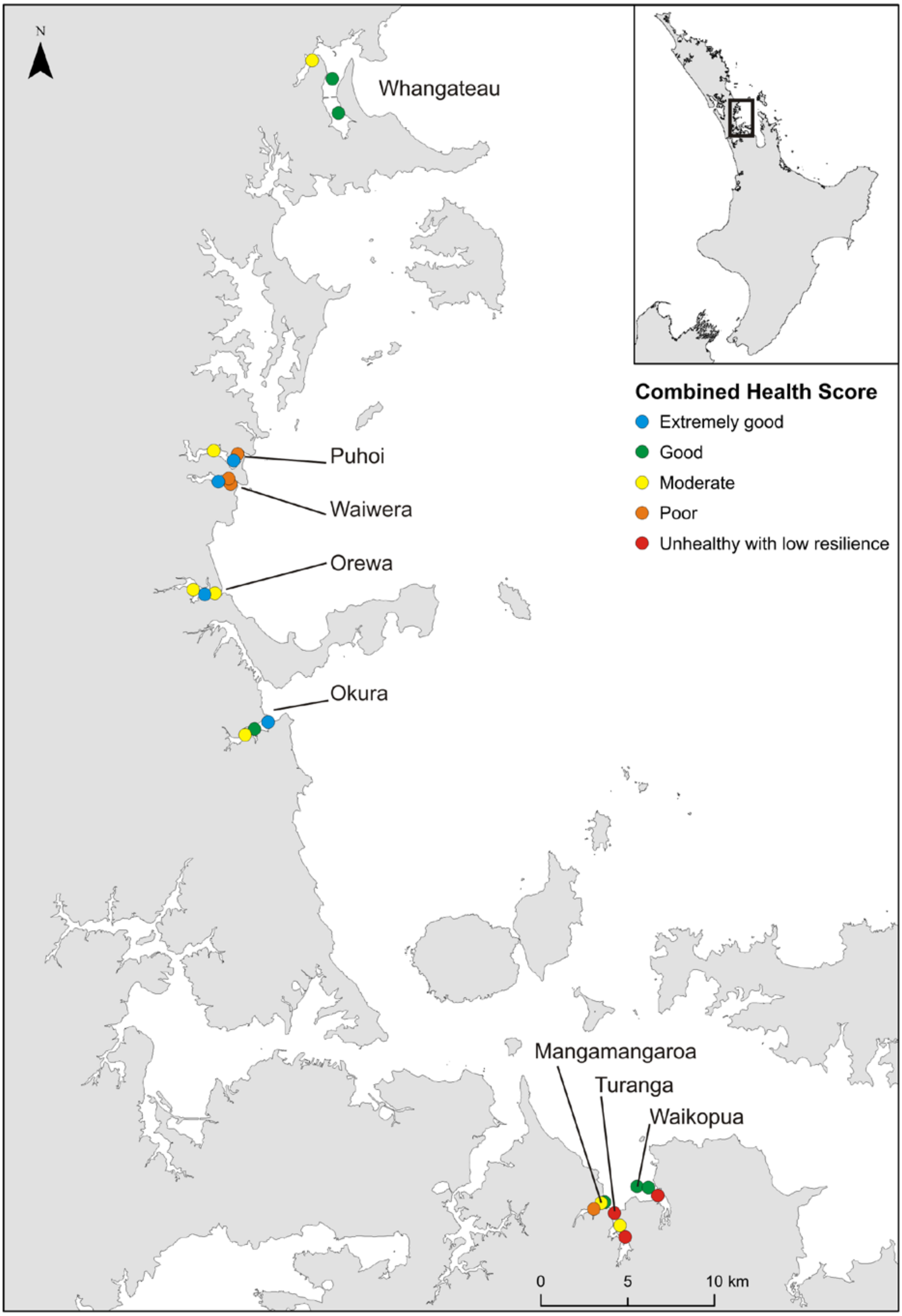

Figure 3-5: Combined health scores calculated for 3 sites from each estuary from 2015 data.

4.0 Are there changes over time associated with increased sedimentation?

As a time series increases in length, we expect some previously detected trends to be shown as part of long-term cycles. As well as initial trends becoming part of long term cycles, our ability to monitor changes and detect long term trends, in particular abundances of different sized bivalves, is limited by the biannual sampling. With only two sample times yearly, the potential for abundances to move between categories (as bivalves grow) and create apparent increases in annual maxima in different size classes is enhanced. Moreover, up till 2010, sampling was not standardised to particular months (e.g., October, April) but could have occurred anytime during a three month seasonal window. These factors make analysis of changes over time in bivalve size classes less robust and more prone to the detection of spurious trends. Thus, in this report, changes in bivalve size classes will only be analysed and discussed to provide context for trends in their total abundance.

The 2012 report noted that decreases in sediment mud content (particles sized <63 µm) and increases in the very fine sand content (particles sized 63 -124 µm) were observed. As the very fine sand fraction is also often a part of the terrestrial sediment load in the Auckland region (Lohrer et al. 2004), trend analysis was also done on the sum of the mud and very fine sand portions of the sediment (<125 µm).

Here we discuss the trends detected in data from spring 2004 to spring 2015. As changes in Okura were the initial focus of this monitoring programme, we report on changes in Okura first, followed by the other estuaries from north to south. For each estuary we report on (1) trends consistent with increased sedimentation, and (2) trends not consistent with increased sedimentation. At the end of 2015, 45 of the 73 trends previously reported using data to the end of 2013 (Hewitt et al. 2014b) that were thought to represent responses to increased sedimentation were still detected. A further 13 new trends related to increased sedimentation were also detected. The disappearance of previously reported trends is discussed in Appendix 7.3.

4.1 Okura

Figure 4-1: Location of sites in Okura Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30% brown, and 30 to 40% red. All sites in Okura are now sampled, the core sites, sampled on each sampling occasion are circles, and the rotational sites are marked with triangles.

Trends consistent with increased sedimentation were detected at all ten sites[1] in Okura (see Table 4-1) (Figure 4-1). Increasing trends of very fine particles (very fine sand + mud) were detected at 7 of the 10 sites (all sites except site 1, 4 and 7). A decreasing trend for CAPmud was detected at sites 2, 4, 6, 9 and 10, and for the number of taxa at site 9 (Figure 4-2). Both site 1 and 7 showed decreasing trends in the abundance of *Aonides*; at site 1 a linear trend was detected, while at site seven a step trend occurred between 2008-2010 (Figure 4-2). At site 1 a decreasing trend in *Austrovenus* was detected and can be attributed to a decrease of individuals in both the medium and large size class (Figure 4-2). Data shows low recruitment of *Austrovenus* juveniles at sites 1, 2, 8 and 9 since April 2014 (< 5 individuals per sampling time). This low recruitment is likely to move through the different size classes over the next two years and if it persists will be reflected in decreases in the total abundance of *Austrovenus*. Site 4 data exhibited an increasing trend in Nereididae (Figure 4-2).

[1] The time series record for non-core sites 5, 6 and 10 is patchy as these sites have only recently become permanently sampled.

Of the 29 trends detected in Okura, 13 were not consistent with increased sedimentation and these were generally related to the number of taxa (increasing at sites 3, 6 and 7) and sediment mud content (decreasing at sites 1, 5, 6 and 7). The majority of inconsistent trends were found at site 7, which had only one trend consistent with increased sedimentation (Table 4-1).

Table 4-1: Statistically significant trends detected at Okura sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation,* may be a multi-year cycle and # are step trends.

	1	2	3	4	5	6	7	8	9	10
Community Composition (CAPmud)		-0.15		-0.11*		-0.15			-0.20	-0.21
# taxa			5.2			8.0	5.8		-11.5	
Aonides	-17.4#						-22.1#			
Austrovenus	-16.2		19.4			26.1				
Macomona				4.1			2.1			
Nereididae				1.2						
Paphies							1.6			
Sediment mud content	-7.5				-6.7	-6.4	-10.1			
Sediment very fine sand + mud		28.0	32.3		9.3	14.9		46.2	54.4	43.1

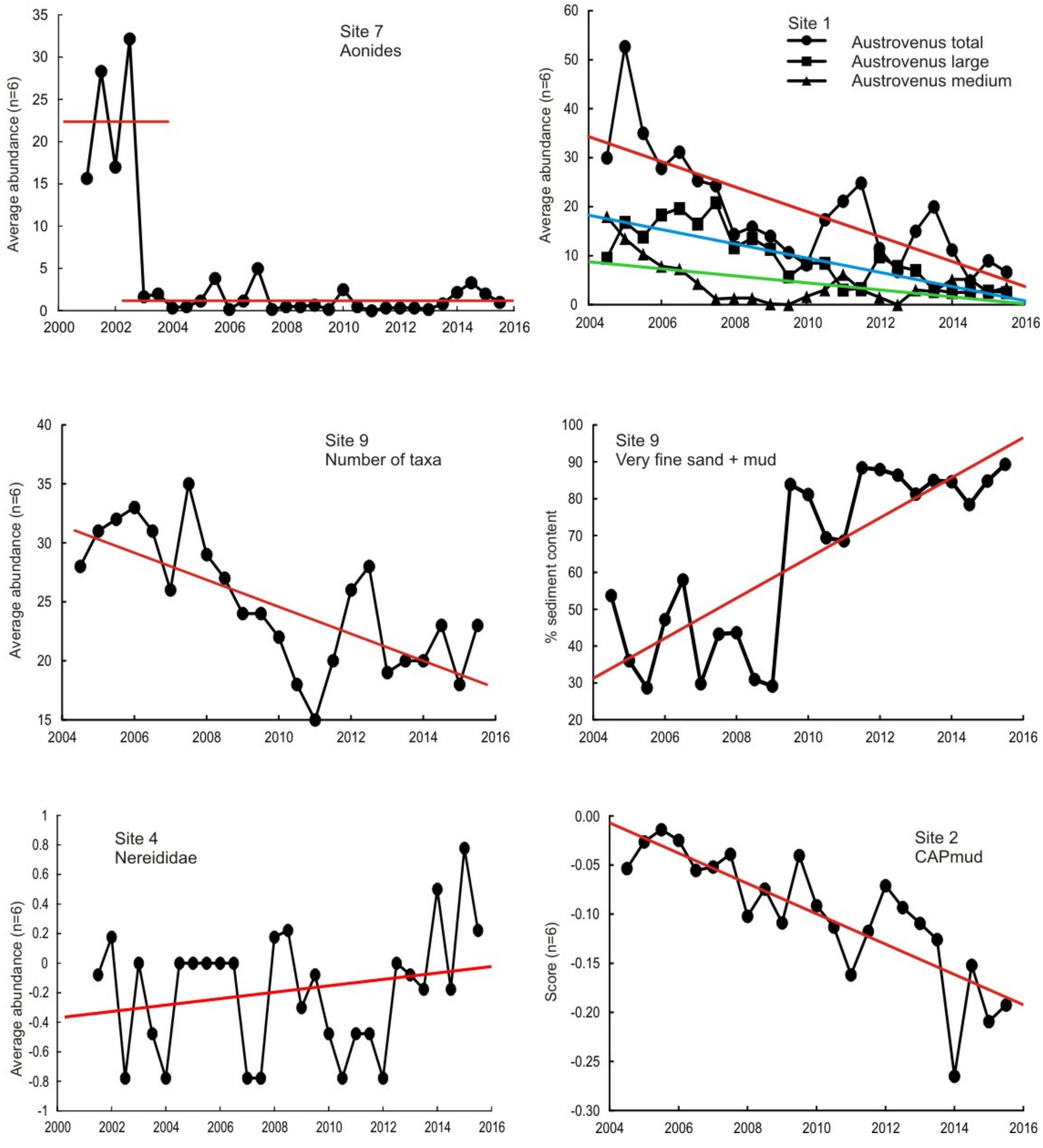

Figure 4-2: Examples of trends consistent with increased sedimentation detected at Okura sites, data for Nereididae was log transformed.

4.2 Whangateau

Figure 4-3: Location of sites in Whangateau Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10% blue, 10 to 20% orange, 20 to 30 brown%, and 30 to 40% red. Sites with black rings are those presently sampled.

This is the first year that sites in Whangateau have been included in the trend analysis section of this report (Figure 4-3). While there is a sufficient record for trend analysis (13 sample points), any trends detected may still be sections of multi-year cycles.

Five trends consistent with increased sedimentation were detected (Table 4-2), two of which were at site 1 where an increasing trend in Nereididae (Figure 4-4) and a decreasing step trend in CAPmud (step occurred in April 2004) was detected. Data from sites 5 and 7 show decreasing trends in CAPmud (Figure 4-4), while data on the abundance of *Anthopleura* at site 4 also showed a decreasing trend (Figure 4-4).

A further 7 trends not consistent with increasing sediment were found at Whangateau, most of which occurred at site 5. Trends of increasing abundance of *Austrovenus* were detected at sites 1, 5 and 7 and for number of taxa at sites 4 and 5. Increases in abundance of *Macomona* and *Anthopluera* were also detected at site 5. The increase in *Macomona* occurred across all size classes. In fact all of the sites showed increasing trends within multiyear cycles for small *Macomona* and a step trend increase for medium and large *Macomona* (occurring between April 2011 and October 2012). A significant increase in abundance of *Anthopleura* at site 5 is most likely related to increases in *Austrovenus* as this anemone is generally found on *Austrovenus* shells. No significant trends (<0.05) in sediment mud or very fine particle content was found at any of the monitored sites.

Table 4-2: Statistically significant trends detected at Whangateau sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation,* may be a multi-year cycle and # are step trends.

	1	4	5	7
CAPmud	-0.06#		-0.26	-0.18
# taxa		14.07	14.07	
Anthopleura		-7.55	10.55	
Austrovenus	6.87		10.26	7.47
Macomona			4.89	
Nereididae	16.78			

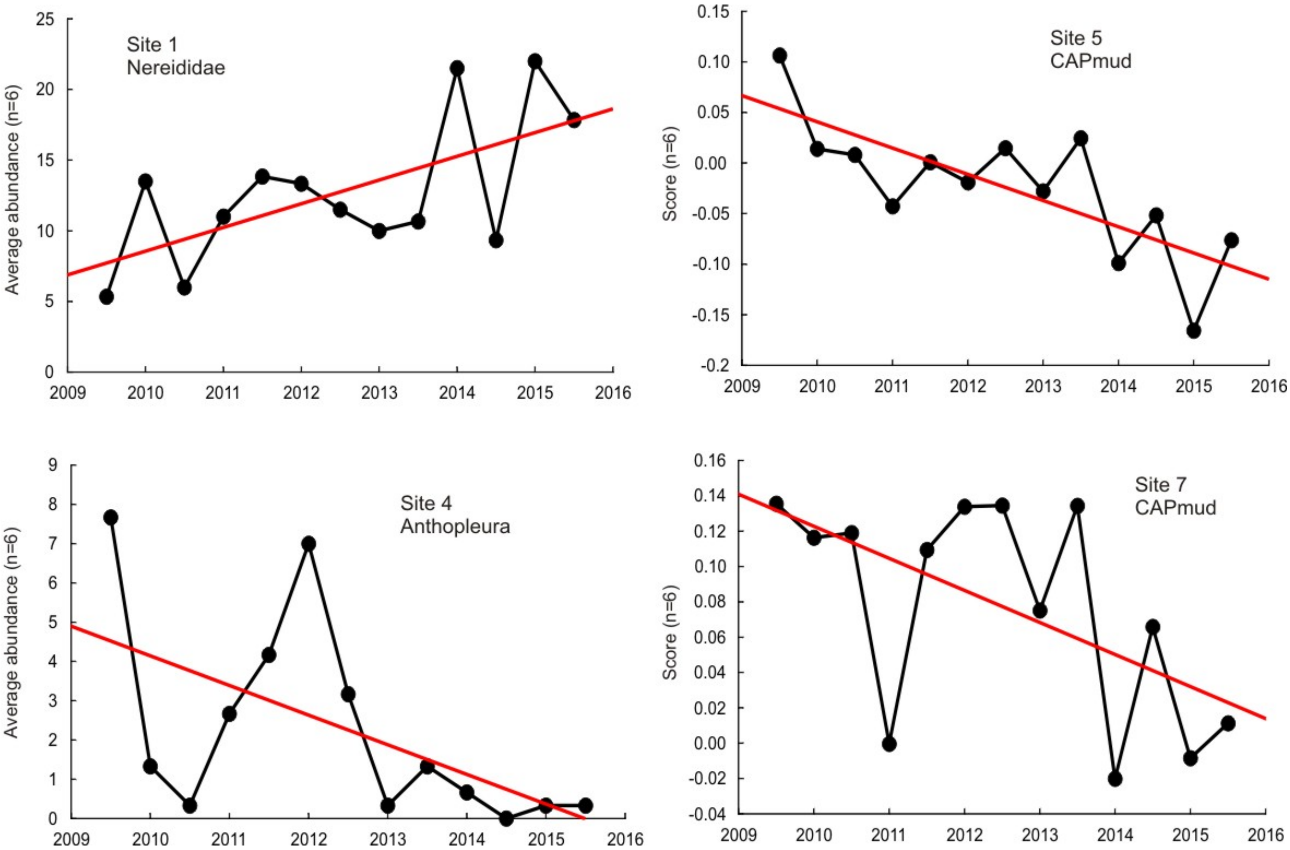

Figure 4-4: Examples of trends consistent with increased sedimentation detected at Whangateau sites.

4.3 Puhoi

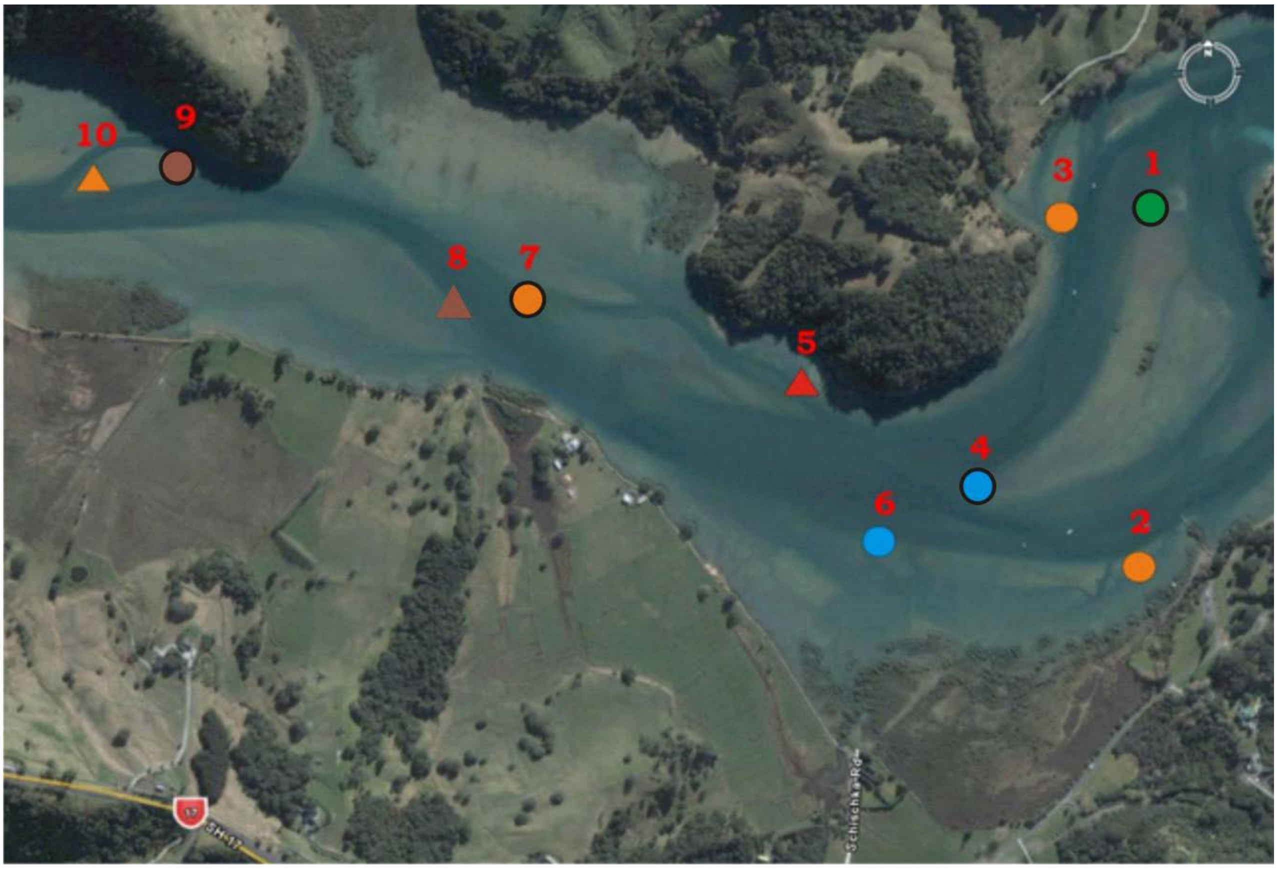

Figure 4-5: Location of sites in Puhoi Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Five trends consistent with increasing sedimentation were found at the monitored sites in Puhoi (Figure 4-5). At site 7 decreasing trends in CAPmud, number of taxa and very fine particles were detected. Another decreasing trend in CAPmud was detected at site 1 and a decreasing trend in the abundance of *Waitangi* was detected at site 4 (Table 4-3) (Figure 4-6).

No trends related to sedimentation were detected at site 9. Two trends were detected that were not consistent with increased sedimentation. Increasing abundances of total *Austrovenus* were detected at sites 4 and 7. The increases in abundance of *Austrovenus* occurred across the size classes.

Table 4-3: Statistically significant trends detected at Puhoi sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation. * may be a multi-year cycle.

	1	4	7	9
CAPmud	-0.05*		-0.10	
# taxa			-7.17	
Austrovenus		68.10	7.77	
Waitangi		-20.77		
Sediment very fine sand + mud			32.07	

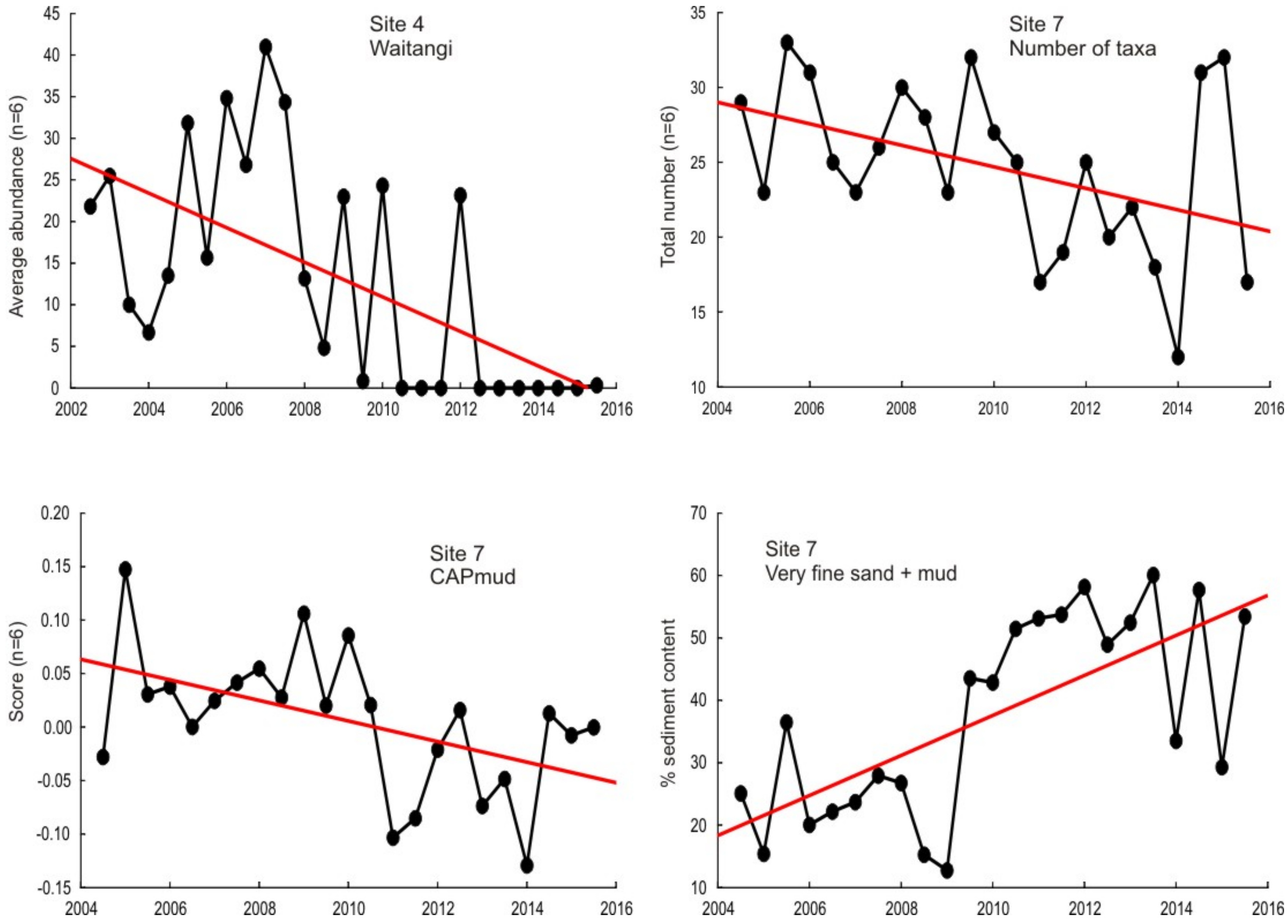

Figure 4-6: Examples of trends consistent with increased sedimentation detected at Puhoi sites.

Waiwera

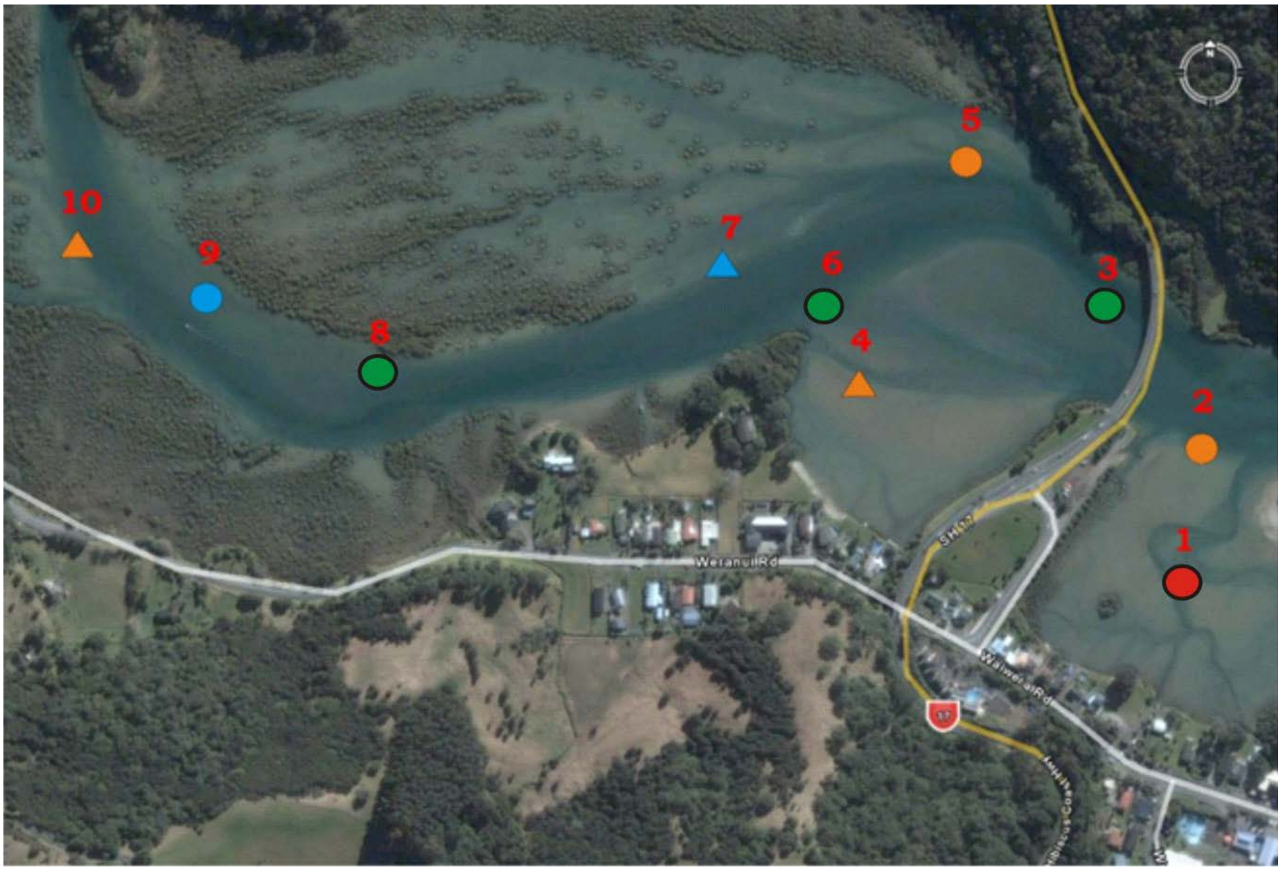

Figure 4-7: Location of sites in Waiwera Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5% to 10% blue, 10% to 20% orange, 20% to 30% brown, and 30% to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Ten trends consistent with increasing sedimentation were detected in the data obtained from sites within the Waiwera estuary (Table 4-4, Figure 4-7). At sites 1, 6 and 8 a decreasing trend in CAPmud was detected along with a decreasing trend in the number of taxa at site 1 (Figure 4-8). Increasing trends in the abundance of Nereididae was detected at site 6 and 8 and decreasing trends in *Waitangi* and *Colurostylis* were detected at site 3 and 8 respectively (Figure 4-8). At site 1 both mud content and very fine sand + mud showed increasing trends (Figure 4-8).

While the largest number of trends were detected from site 8 (8 trends), most of these were not consistent with sedimentation; increasing trends in the total abundance of *Anthopleura*, *Macomona* and *Austrovenus*, and a decreasing trend in mud content. The increases in *Austrovenus* occurred in all size classes, whereas the increase in abundance of *Macomona* was of large individuals. An increase in abundance of *Anthopleura* was also detected at site 6 and decreasing trends in sediment mud content were detected at sites 3 and 6 (Table 4-4).

Table 4-4: Statistically significant trends detected at Waiwera sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation. * may be a multi-year cycle.

	1	3	6	8
CAPmud	-0.13		-0.10	-0.10
# taxa	-5.6*			7.5
Anthopleura			1.5	3.3
Austrovenus				28.5
Colurostylis				-15.6
Macomona				2.9
Nereididae			2.4	6.4
Waitangi		-12.6		
Sediment mud content	11.9	-7.7	-8.8	-2.5
Sediment very fine sand + mud	22.3			

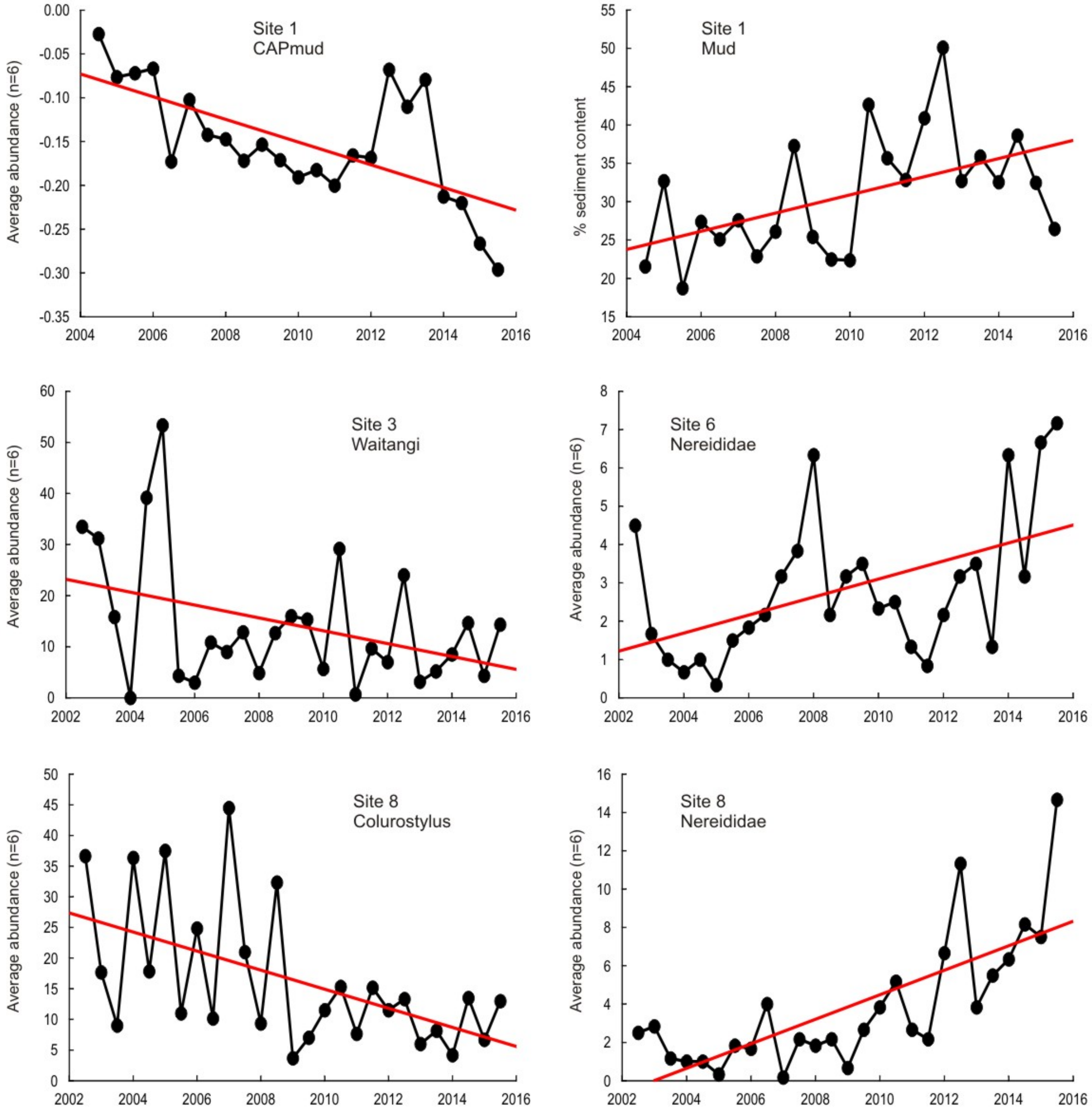

Figure 4-8: Examples of trends consistent with increased sedimentation detected at Waiwera sites.

4.4 Orewa

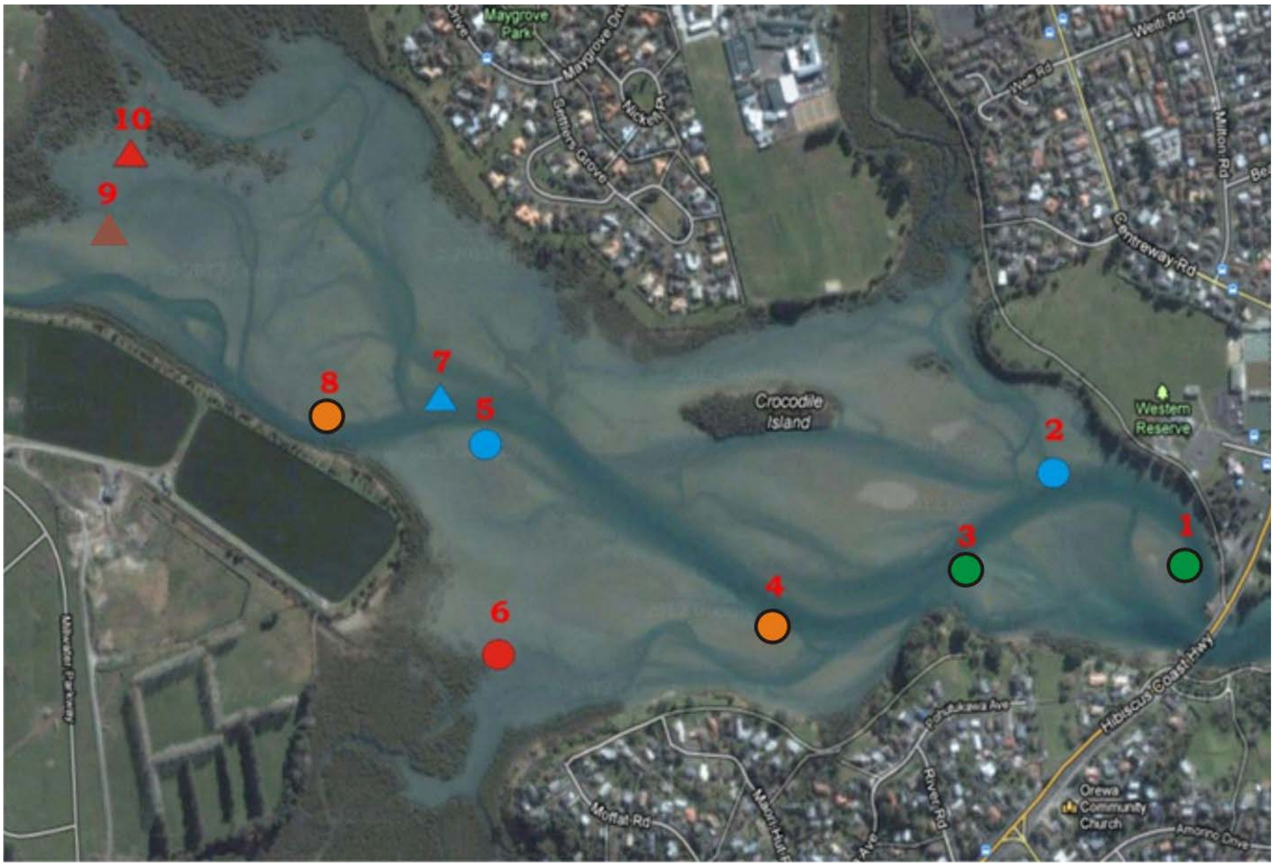

Figure 4-9: Location of sites in Orewa Estuary. Sites are colour coded to show average sediment mud content: <5% green, 5 to 10 blue, 10 to 20 orange, 20 to 30 brown, and 30 to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Of the 14 trends detected in the Orewa data, half were consistent with increasing sedimentation (Figure 4-9) (Table 4-5). At site 1 the two trends detected were both consistent with increasing sedimentation; (decreasing trends in CAPmud and abundances of *Waitangi*). Decreasing trends in the abundance *Waitangi* were also observed at sites 3 and 4; at site 3 this was a step trend which occurred in April 2014 where the average abundance went from 12.2 to 0.4. At site 4 decreasing trends in the abundance of *Paphies* (mainly small) were detected and numbers have been low/absent since 2008-2009 (Figure 4-10). At sites 4 and 8, increasing trends in very fine sand + mud particles were detected.

Trends not consistent with increasing sedimentation were detected only at sites 4 and 8. Decreases in mud content and increases in the abundances of *Anthopleura* were detected at both sites. At site 8 increases in the abundances of both *Macomona* and *Austrovenus* were also detected. For *Austrovenus* increases in the abundances of all size classes increased, but for *Macomona* this was only an increase in juveniles.

Table 4-5: Statistically significant trends detected at Orewa sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2 Highlighted values are those consistent with increased sedimentation,* may be a multi-year cycle and # are step trends.

	1	3	4	8
CAPmud	-0.06			
# taxa			12.35	
Anthopleura			1.89	2.77
Austrovenus			24.57	
Macomona			3.14	
Paphies			-15.49	
Waitangi	-30.12	-11.77#	-31.05	
Sediment mud content			-13.87	-15.01
Sediment very fine sand + mud			32.08	39.43

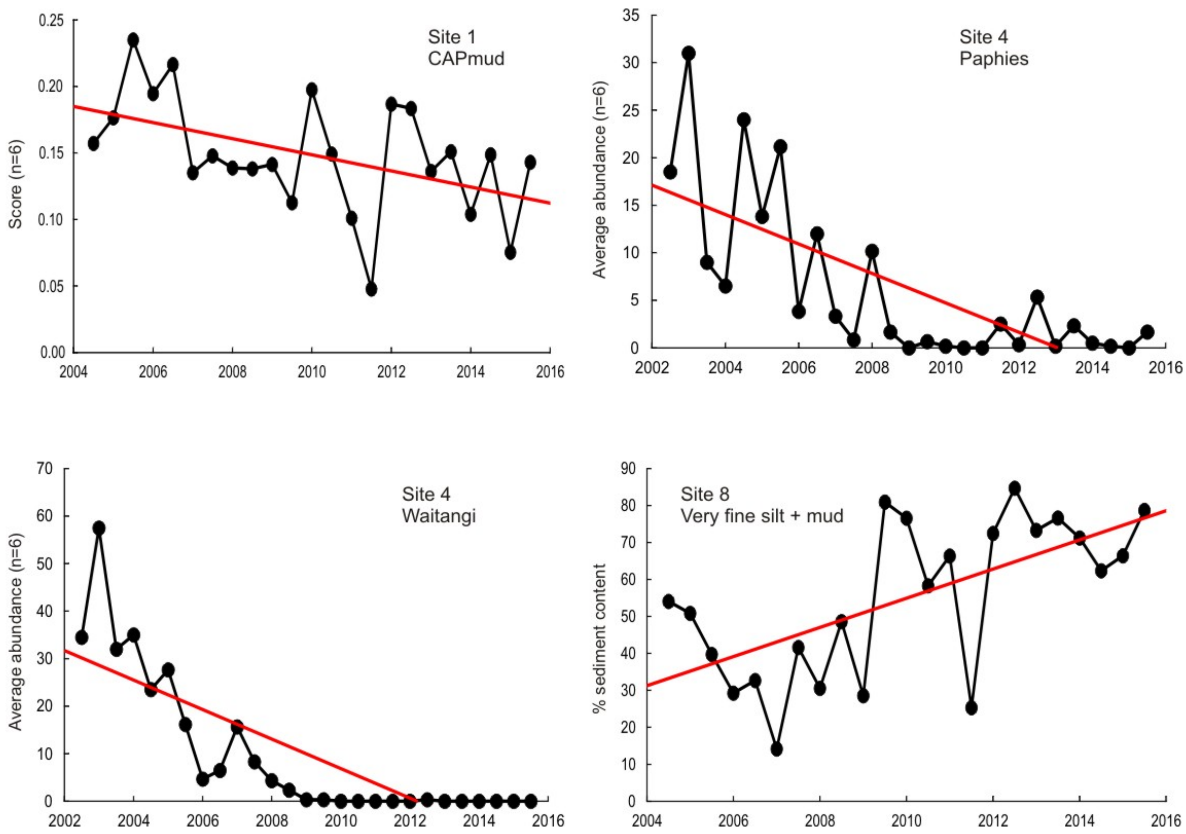

Figure 4-10: Examples of trends consistent with increased sedimentation detected at Orewa sites, data for *Paphies* and *Waitangi* at site 4 was log transformed.

4.5 Mangemangeroa

Figure 4-11: Location of sites in Mangemangeroa Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5% to 10% blue, 10% to 20% orange, 20% to 30% brown, and 30% to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

At Mangemangeroa all of the trends found are consistent with increasing sedimentation, with the exception of a decreasing trend in Nereididae (at site 6) (Table 4-6, Figure 4-11). CAPmud and very fine sand + mud showed trends at sites 5, 6 and 9. Site 5 and 6 showed decreasing trends in CAPmud with a step change at site 5 in April 2009 (from -0.10 to -0.18) (Figure 4-11). Site 5 showed a decreasing trend in the number of taxa as did the abundance of *Aonides* at site 3. Site 5, 6 and 9 showed increasing trends in very fine sand + mud, with site six exhibiting a step trend in April 2009 (from 28% to 59%) (Figure 4-11).

Table 4-6: Statistically significant trends detected at Mangemangeroa sites in data collected from October 2004 to October 2015 for community composition, number of taxa, the abundance of the selected species and specific sediment fractions. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation,* may be a multi-year cycle and # are step trends.

	3	5	6	9
CAPmud		-0.08#	-0.16	-0.11
# taxa		-9.82		
Aonides	-6.60#			
Nereididae			-2.67	
Sediment very fine sand + mud		39.55	30.87#	42.53

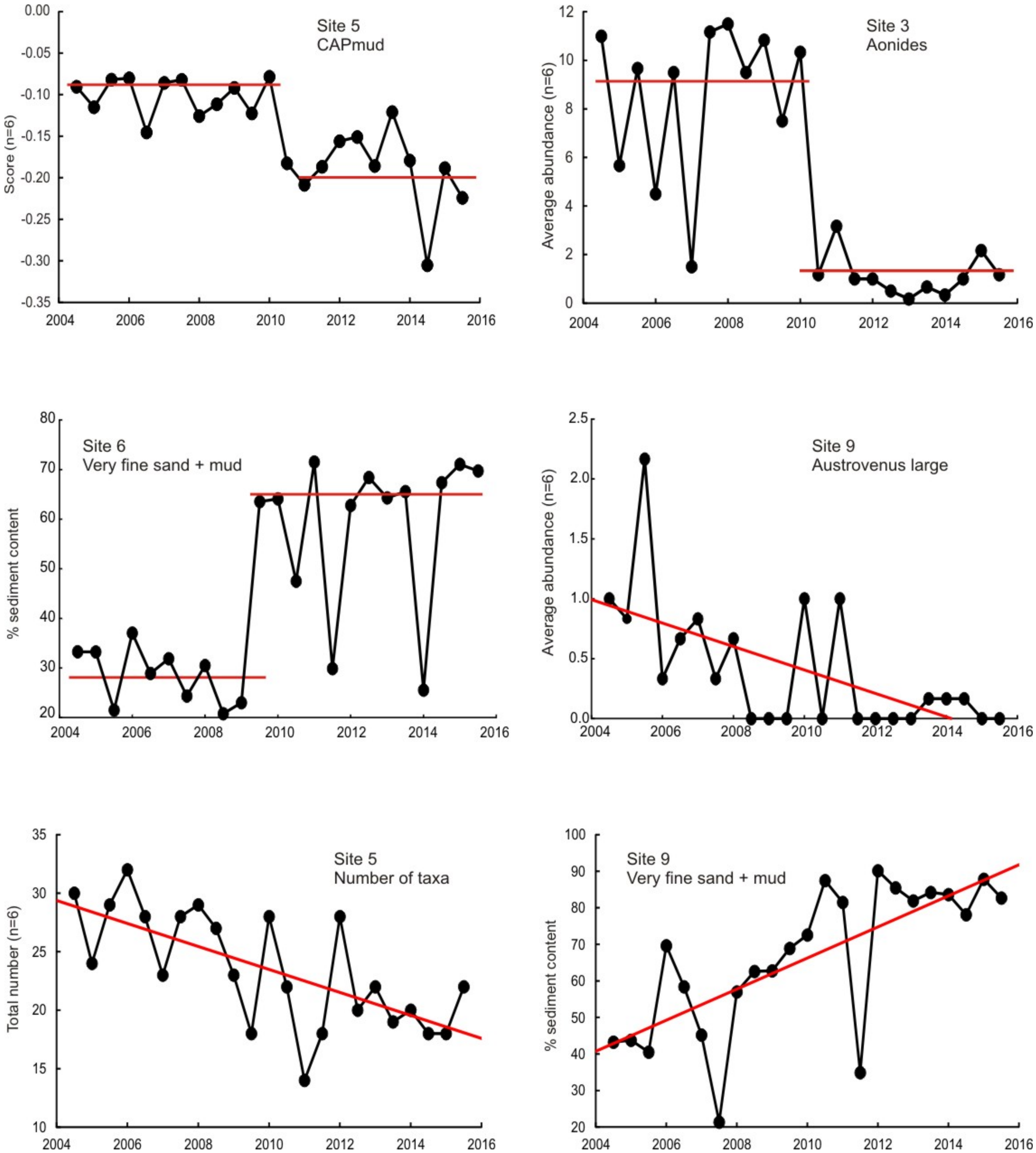

Figure 4-12: Examples of trends consistent with increased sedimentation detected at Mangemangeroa sites.

4.6 Turanga

Figure 4-13: Location of sites in Turanga Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5% to 10% blue, 10% to 20% orange, 20% to 30% brown, and 30% to 40% red. Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Nine trends consistent with increasing sedimentation were found at the Turanga monitoring sites (Table 4-7, Figure 4-13). All four of the sites showed increasing trends in very fine particles (very fine sand + mud), with both site 4 and 7 having step trends occurring in October 2009 (increases of 45% and 29%, respectively) (Figure 4-14). Decreasing trends in CAPmud were detected at sites 4, 7 and 8 (Figure 4-14), and a decreasing trend in the number of taxa was detected at site 8. Site 1 showed an increasing trend for mud content (Figure 4-14).

Trends inconsistent with increased sedimentation related to abundances of *Anthopleura* were detected at sites 1 and 7.

Table 4-7: Statistically significant trends detected at Turanga sites in data collected from October 2004 to October 2015 for community composition, number of taxa and the abundance of the selected species. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Highlighted values are those consistent with increased sedimentation,* may be a multi-year cycle and # are step trends.

	1	4	7	8
CAPmud		-0.17	-0.15	-0.10
# taxa				-6.15#
Anthopleura	5.97		6.38	
Sediment mud content	5.43			
Sediment very fine sand + mud	37.32	44.98#	28.60#	29.65

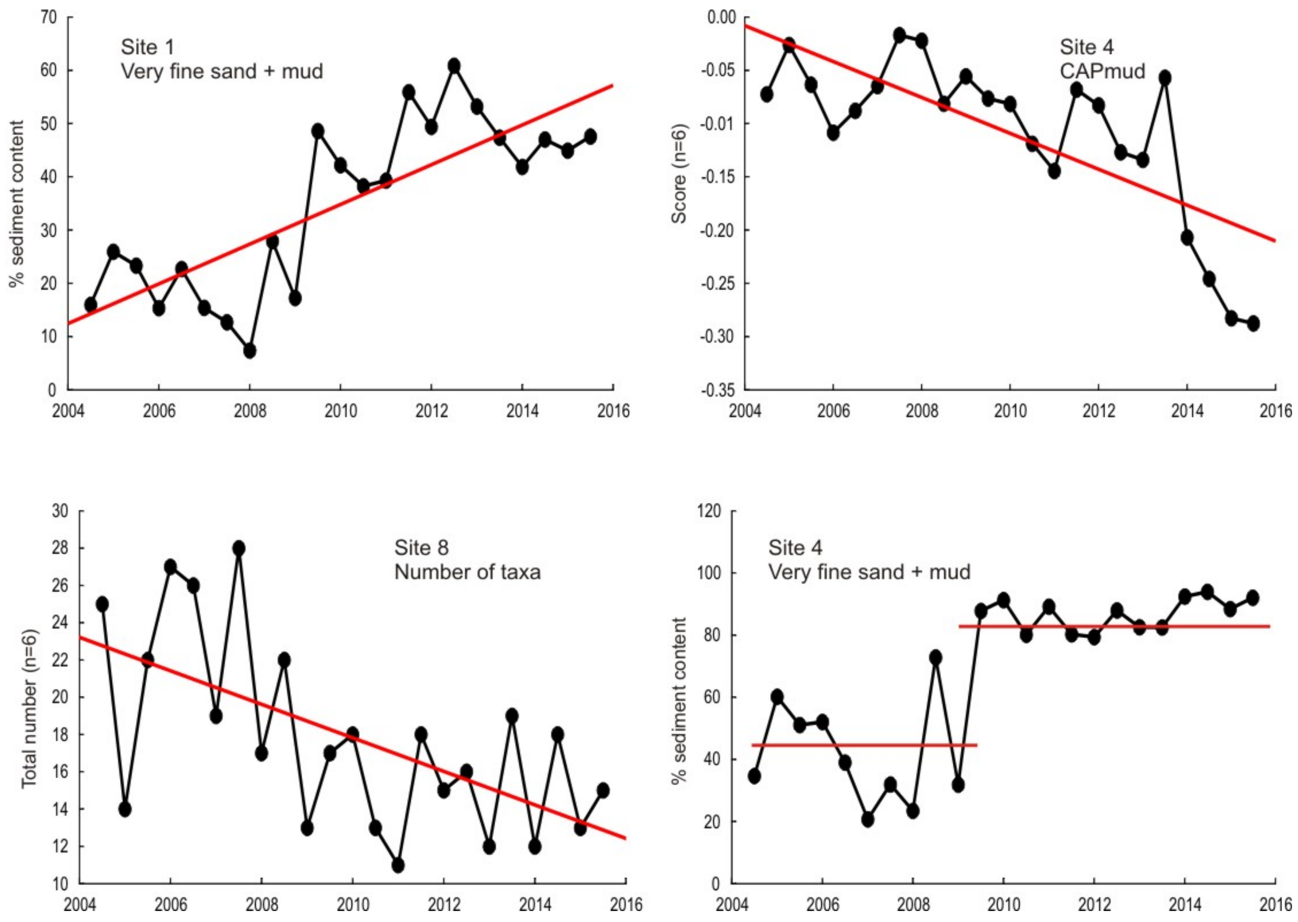

Figure 4-14: Examples of trends consistent with increased sedimentation detected at Turanga sites.

4.7 Waikopua

Figure 4-15: Location of sites in Waikopua Estuary. Sites are colour coded to show average sediment mud (<63µm) content: <5% green, 5% to 10% blue, 10% to 20% orange, 20% to 30% brown, and 30% to 40% red Core sites (sampled until September 2014) are circles, rotational sites are marked with triangles and sites with black rings are presently sampled.

Of the 9 trends detected at the Waikopua monitoring sites, six were consistent with increased sedimentation (Table 4-8, Figure 4-15). Increases in very fine sand + mud were detected at all four sites (for examples see Figure 4-16). Decreasing trends in CAPmud and number of taxa were detected at sites 9 and 3, respectively (Figure 4-16).

Trends not consistent with increasing sedimentation include: increasing abundance of *Anthopleura* and decreasing mud content at site 3, and increasing abundance of *Austrovenus* at site 6. The increased abundance of *Austrovenus* was a result of increases in all size classes.

Table 4-8: Statistically significant trends detected at Waikopua sites in data collected from October 2004 to October 2015 for community composition, number of taxa and the abundance of the selected species. Values given are the predicted change over the 10 years of sampling per core, p-values are given in Appendix 7.2. Values with an *, while having p- values <0.05, have residuals that show temporal patterns and are thus potentially part of longer term cycles, rather than consistent trends. Highlighted values are those consistent with increased sedimentation.

	1	3	6	9
CAPmud				-0.11
# taxa		-7.30		
Anthopleura		1.30		
Austrovenus			3.69	
Sediment mud content		-11.91		
Sediment very fine sand + mud	22.62	34.34	37.31	36.56

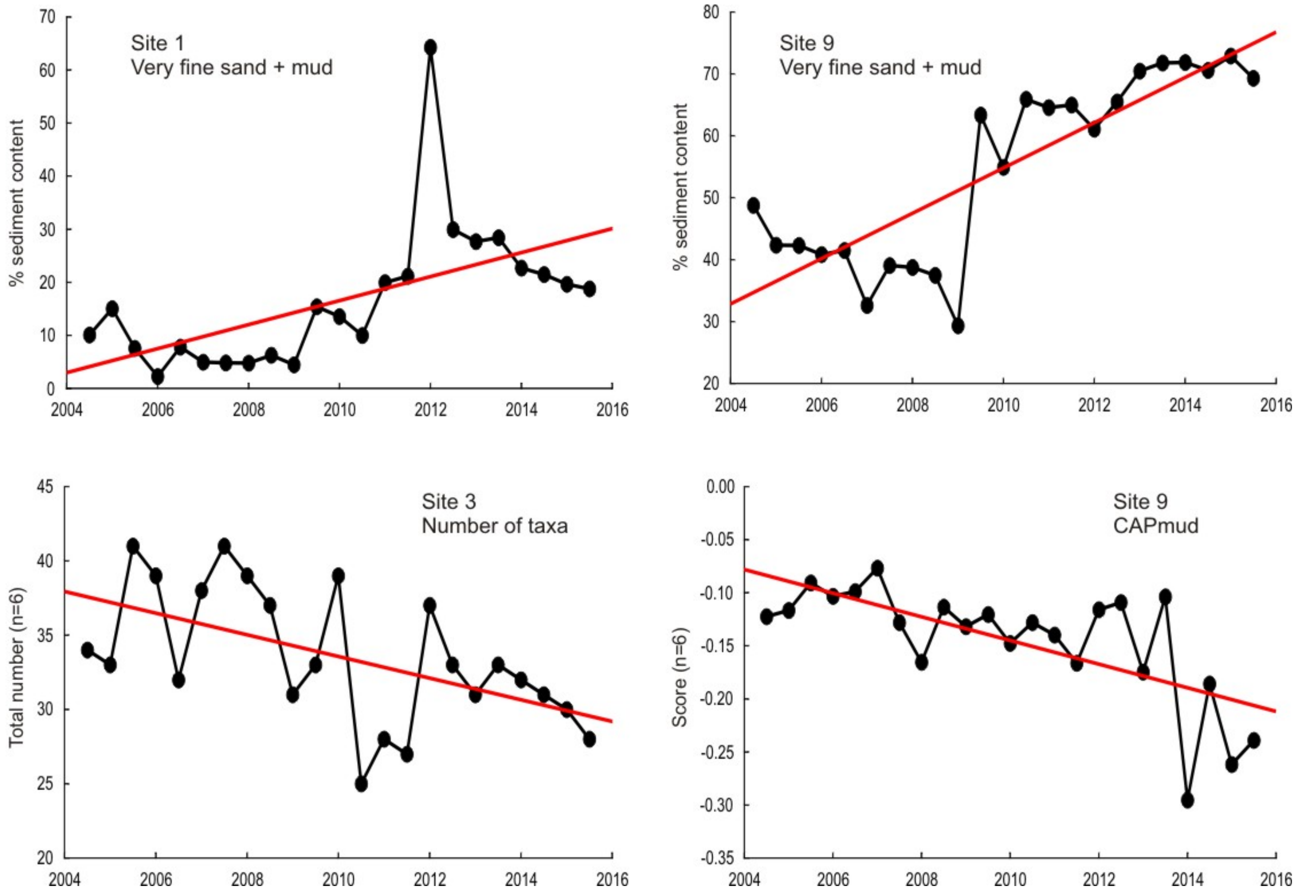

Figure 4-16: Examples of trends consistent with increased sedimentation detected at Waikopua sites.

4.8 Summary

The previous report found several increases in the number of taxa and raised a query as to the robustness of this variable due to the varying degrees of taxonomic resolution in operation during the length of the time series (due to changes in research providers and taxonomists). However, in the present analysis, increasing trends in the number of taxa were observed from two of the sites in the Whangateau estuary which has only been analysed by one provider. This leads us to suggest that some broad-scale factors affecting number of taxa in a positive fashion may be operating over the study area (e.g., increasing temperature, changes in storm frequency). Hewitt et al. (2014) observed that the number of taxa is one of the variables that is most strongly driven by climate fluctuations. The influence of this broad-scale factor would reduce the likelihood that we would be able to detect decreases in number of taxa associated with sedimentation.

Reporting on trends is complicated by the potential to detect parts of long-term cycles as a continuous trend, especially where long-term climatic variation can affect the measured variable. Long-term cycles (7 -12 years) have been observed in species abundances in the Manukau Harbour Ecological Monitoring Programme (Hewitt & Thrush 2009, Hewitt & Hailes 2007), and cycles such as these would generally be detected as trends with less than 10 years of data, as we have here. Such long-term cycles can result in trends that were previously detected (with a shorter time series) no longer being detected, and in new trends being detected with residuals suggesting cyclic patterns. The appendix details the numbers of trends consistent with increased sedimentation reported in Hewitt & Simpson (2012) for each of the selected taxa and the two community variables, together with the number still detectable in the analysis of data to October 2015. Importantly, while a large number of trends were previously detected for the number of taxa, very few (<10 %) were detected with an additional two years of data.

The majority of the trends consistent with sedimentation have magnitudes that are ecologically significant, i.e., changes in: abundance of >10 individuals per core; >5 taxa per core; >10% in CAPmud score; or >10% change in sediment content. Removing all new trends that we are not confident in (based on residuals), as well as all trends that we do not define as ecologically significant, we find that the highest number of trends consistent with increased sedimentation detected at a single site is three. Sites exhibiting this number of trends occur in all estuaries except Whangateau and Waikopua. The number of trends in an estuary is highest in Okura, with 15 trends (because ten sites are sampled), followed by Turanga with nine trends. Whangateau and Puhoi exhibit the lowest number of trends. However, for Okura, it is important to note that all 10 of the sites have at least one trend detected that is consistent with sedimentation and there are 7 sites which have increases in the percentage of very fine sediment.

A more conservative summary can be obtained by only considering the number of sites with more than one trend consistent with increased sedimentation, unless the only trend is a step change, when the site is included in the count. The estuaries with the highest number of these sites are Turanga (4 out of 4 sites), Okura (6 out of 10 sites), Orewa and Mangemangeroa (3 of the 4 sites each). These results suggest that, conservatively, Okura, Turanga, Orewa and Mangemangeroa are exhibiting the most on-going change consistent with increased sedimentation.

However, this should be supplemented by considering the number of trends that are at the community level (i.e., decreases in CAPmud or number of taxa). For all estuaries (except Okura, Orewa, Puhoi and Waikopua) trends in one or both of these variables were detected at 3 of the 4 sites). For the others, Puhoi, Orewa and Waikopua had a trend detected in one of these variables at 1 of 4 sites, Okura had trends detected at 40% of sites. Additionally it is possible that some of the trends inconsistent with sedimentation may be due to species having higher tolerances for very fine sand particles than for mud sized particles. It should also be noted that the effects of sedimentation are not limited to sites in the upper reaches of the estuaries as sites 1-4, which could be considered to be outer sandy sites in many of the estuaries, show a number of significant trends consistent with increased sedimentation.

Table 4-9: Numbers of trends that we are confident in that are consistent with increased sedimentation and are ecologically significant (see section 4.9 for definition). Values with a # are sites when the only trend is a step trend, sites not monitored are marked with N.

Sites	Okura	Whangateau	Puhoi	Waiwera	Orewa	Mangemangeroa	Turanga	Waikopua
1	2	2	0	3	2	N	2	1
2	2	N	N	N	N	N	N	N
3	1	N	N	1	1#	0	N	2
4	0	0	1	N	3	N	2	N
5	1	1	N	N	N	3	N	N
6	2	N	N	1	N	2	N	1
7	1#	1	3	N	N	N	2	N
8	1	N	N	2	1	N	3	N
9	3	N	0	N	N	2	N	2
10	2	N	N	N	N	N	N	N
Total number of trends	15	4	4	7	7	7	9	6
Number of sites with more than one trend, or a step trend	6	1	1	2	3	3	4	2

5.0 Summary and recommendations

5.1 Summary of status

The estuaries separate into three groups based on chlorophyll *a* content of the sediment with Turanga and Mangemangeroa having the highest values and Whangateau, Orewa, Waiwera, Waikopua and Puhoi the lowest. There are no consistent changes moving along the estuarine gradient. Percent organic matter varies little across the estuaries and is generally < 5%. The estuaries also overlap strongly in grain size characteristics, with a general tendency for sites furthest up the estuaries to have higher average mud and very fine sand content, as opposed to those closest to the mouth, which have more fine sands.

Generally the estuaries are in moderate to good health. Okura had one site rated “extremely good” (site 1 at the mouth of the estuary) with respect to heavy metals and two sites rated “extremely good” with respect to mud content. No sites in Okura rated below “moderate” in terms of heavy metals or mud, with the majority of sites being rates as “good”. All sites in Okura were rated highly in terms of functionality.

Whangateau and Orewa were rated “moderate’ to “extremely good” with respect to mud content, and all sites in Whangateau were rated high in terms of functionality. Only Orewa, Turanga, Waiwera and Waikopua contained some sites of low functionality. Puhoi, Orewa and Whangateau were rated healthiest in terms of metal contamination.

Combining these indices into the single health score resulted in sites in estuaries varying from poor to extremely good. Waiwera, Turanga, Mangemangeroa and Waikopua estuaries stand out as having at least one site with a low health rating. All three of these estuaries contain a site rated “poor” and neither Turanga, Mangemangeroa nor Waikopua had sites rated as “extremely good”. Okura ranged from moderate to extremely good health, moving towards the mouth of the estuary, with no sites rated as poor.

We are reasonably confident about the scoring for all estuaries with the exception of Whangateau and Waikopua where the degree of fit between the BHM model predictions of heavy metals and mud content suggest that the degree of health may be underestimated (Hewitt & Simpson 2012). It is important to recognise that the health scores are from particular sites within each estuary, and do not necessarily represent the health status of each estuary as a whole. There may be locations in each estuary that are significantly healthier, or less healthy, than the monitored sites.

5.2 Changes consistent with increased sedimentation

The number of trends consistent with increased sedimentation and likely to be ecologically significant (see section 4.9 for definition) is highest in Okura, as this has ten monitoring sites, followed by Turanga (9 trends), with Puhoi and Whangateau having the lowest number of these trends. In Turanga more than one trend consistent with increased sedimentation was detected at all sites; in Orewa and Mangemangeroa more than one trend consistent with increased sedimentation was detected at 3 of the 4 sites. Turanga, Waiwera, Mangemangeroa and Whangateau also exhibited trends consistent with sedimentation in community level indicators (CAPmud and/or number of taxa) at 3 of the 4 sites.

Table 5-1: Summary of ecologically significant trends consistent with sedimentation as a proportion of the number of sites monitored. Highest values are highlighted.

Estuary	Proportion of trends	Proportion of sites with more than one trend	Proportion of sites with trends at community level
Okura	1.50	0.60	0.40
Whangateau	1.00	0.25	0.75
Puhoi	1.00	0.25	0.25
Waiwera	1.75	0.50	0.75
Orewa	1.75	0.75	0.25
Mangemangeroa	1.75	0.75	0.75
Turanga	2.25	1.0	0.75
Waikopua	1.50	0.50	0.25

Overall, there are changes of concern at Okura in terms of the number of sites exhibiting trends consistent with sedimentation because all sites exhibit at least one trend although they are not all likely to be ecologically significant. Also changes in community composition consistent with increasing mud content are found at nearly half the sites; and increases in very fine sediment particles were detected at 7 of the ten sites. But changes observed in Turanga are also of concern as this estuary has the highest proportion trends and proportion of sites with trends at the community level. Whangateau, Waiwera and Mangemangeroa are also of concern given the proportion of sites that exhibit trends at the community level. The estuary showing the least changes of concern is Puhoi.

With an increased number of monitored years, numbers, specifics of patterns and trends can be expected to alter. In particular, with <10 years of data some detected trends will inevitably turn out to be only part of longer-term cycles. While our focus on trends that are only consistent with increased sedimentation will reduce this variation, it will not eliminate it for two reasons. Firstly, increases in sedimentation will vary not only with catchment activities but also with climatic factors. If catchment activities that generate sediment coincide with heavy rain, higher than normal amounts of sediment will be delivered to the estuary promoting a stronger response from the macrofaunal communities. Secondly, sediment deposited at a site will not necessarily stay at the site and the degree and speed of removal of this sediment will also vary with climatic conditions (especially wave climate). We would expect this to occur mostly at the outer sites in the estuary where wave exposure is generally higher.

5.3 Recommendations for long-term monitoring

The estuarine monitoring programme has provided important information on the health of these estuaries which has informed state of the environment reporting, report cards and the development of the Auckland Unitary Plan. These estuaries remain at risk from sediment derived from rural activities, land-use change and forestry and currently the monitoring is detecting some trends consistent with increased sediment in each of these estuaries. Given these trends in sedimentation and likely land use changes in these catchments we suggest continuing to monitor all estuaries. The temporal dynamics recorded at estuaries and sites with primarily natural variation currently, are extremely useful for placing changes in other estuaries/sites in context and provide a baseline for changes that will likely occur in these catchments in the relatively near future.

At this stage, we do not suggest increasing the number of sites monitored in Whangateau, Turanga, Waiwera or Mangemangeroa, despite the changes observed in these estuaries. If there are proposed developments in specific locations, rotated monitoring at sites nearest to those locations should be considered for reactivation.

6.0 References

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7.0 Appendices

7.1 Sites and GPS co-ordinates

Table Appendix 7-1: Sites and GPS Co-ordinates. Sites marked with a * are not chemistry sampling sites and the Okura sites which are underlined are core sites.

Estuary	Site	Co-ordinates
Mangemangeroa	3	S36 54.660 E174 57.331
	5	S36 54.657 E174 57.233
	6*	S36 54.679 E174 57.205
	9	S36 54.878 E174 56.929
Okura	<u>1</u>	S36 39.924 E174 44.067
	<u>2</u>*	S36 40.105 E174 43.911
	<u>3</u>*	S36 40.062 E174 43.783
	<u>4</u>*	S36 40.100 E174 43.783
	5*	S36 40.083 E174 43.604
	6*	S36 40.223 E174 43.480
	<u>7</u>	S36 40.258 E174 43.313
	<u>8</u>*	S36 40.294 E174 43.197
	<u>9</u>	S36 40.420 E174 43.061
	10*	S36 40.475 E174 42.942
Orewa	1	S36 35.951 E174 41.816
	3*	S36 35.943 E174 41.626
	4	S36 35.992 E174 41.423
	8	S36 35.855 E174 40.979
Puhoi	1	S36 31.612 E174 42.601
	4	S36 31.816 E174 42.440
	7*	S36 31.663 E174 42.009
	9	S36 31.535 E174 41.668
Turanga	1*	S36 54.402 E174 58.486
	4	S36 54.941 E174 57.737
	7	S36 55.378 E174 57.949
	8	S36 55.740 E174 58.234

Estuary	Site	Co-ordinates
Waikopua	1	S36 54.111 E174 58.600
	3	S36 54.286 E174 58.753
	6*	S36 54.297 E174 59.179
	9	S36 54.489 E174 59.560
Waiwera	1	S36 32.561 E174 42.346
	3	S36 32.455 E174 42.303
	6*	S36 32.450 E174 42.158
	8	S36 32.481 E174 41.873
Whangateau	1	S36 21.115 E174 46.356
	4	S36 19.819 E174 45.950
	5	S36 19.382 E174 45.110
	7*	S36 19.005 E174 45.694

7.2 P-values for trend analyses reported in Section 3

Table Appendix 7-2: P- values for trends detected at Okura sites (sites 1, 8 and 4 df =28, 2, 3, 7 and 9 df =29, sites 5, 6 and 10 df=21). See Table 4-1 for estimates of the magnitude of change.

Okura	1	2	3	4	5	6	7	8	9	10
CAPmud		<0.0001		0.0014		0.0001			<0.0001	<0.0001
# taxa			0.0483			0.0491	0.0136		0.0001	
Aonides	<0.0001						0.0017			
Austrovenus	0.0005		0.0011			0.0001				
Macomona				0.0166			0.0101			
Nereididae				0.0203						
Paphies							0.0381			
Sediment mud content	0.0065				0.0032	0.0249	0.0003			
Sediment very fine sand + mud		0.0023	0.0017		0.0139	0.0150		<0.0001	<0.0001	0.0005

Table Appendix 7-3: P- values for trends detected at Whangateau sites (d.f. = 12). See Table 4-2 for estimates of the magnitude of change.

Whangateau	1	4	5	7
CAPmud	0.1023		0.0027	0.0385
# taxa		0.0013	0.0002	
Anthopleura		0.0432	0.0085	
Austrovenus	0.0014		0.0101	0.0383
Macomona			0.0188	
Nereididae	0.0200			

Table Appendix 7-4: P- values for trends detected at Puhoi sites (d.f. = 26). See

Table 4-3 for estimates of the magnitude of change.

Puhoi	1	4	7	9
CAPmud	0.0213		0.0148	
# taxa	0.0443		0.0423	
Austrovenus		<0.0001	0.0394	
Waitangi		0.0008		
Sediment very fine sand + mud			0.0003	

Table Appendix 7-5: P- values for trends detected at Waiwera sites (d.f. = 26). See Table 4-4 for estimates of the magnitude of change.

Waiwera	1	3	6	8
CAPmud	0.0008		0.0002	<0.0001
# taxa				0.0019
Anthopleura			0.0016	0.0002
Austrovenus				<0.0001
Colurostylis				0.0036
Macomona				0.0020
Nereididae			0.0098	<0.0001
Waitangi		0.0469		
Sediment mud content	0.0118	0.0098	0.0124	0.0270
Sediment very fine sand + mud	0.0001			

Table Appendix 7-6: P- values for trends detected at Orewa sites (d.f. = 26). See Table 4-5 for estimates of the magnitude of change.

Orewa	1	3	4	8
CAPmud	0.0233			
# taxa			0.0004	
Anthopleura			0.0006	0.0203
Austrovenus			<0.0001	
Macomona			0.0008	
Paphies			<0.0001	
Waitangi	<0.0001	0.0037	<0.0001	
Sediment mud content			0.0007	0.0072
Sediment very fine sand + mud			0.0049	0.0011

Table Appendix 7-7: P- values for trends detected at Mangemangeroa sites (d.f. = 26). See Table Appendix 7-8: P- values for trends detected at Turanga sites (d.f. = 22). See Table 4-7 for estimates of the magnitude of change.

Turanga	1	4	7	8
CAPmud		<0.0001	<0.0001	0.0011
# taxa				0.0060
Anthopluera	0.0002		0.0176	
Sediment mud content	<0.0001			
Sediment very fine sand + mud	<0.0001	<0.0001	0.0026	0.0008

Table Appendix 7-9: P- values for trends detected at Waikopua sites (d.f. = 22). See Table 4-8 for estimates of the magnitude of change.

Waikopua	1	3	6	9
CAPmud				0.0003
# taxa		0.0077		
Anthopleura		0.0140		
Austrovenus			0.0070	
Sediment mud content		0.0134		
Sediment very fine sand + mud	0.0043	0.0013	0.0003	<0.0001

7.3 Comparison of trends with those reported in data from 2004 to 2011

Analysing data collected over the seven years to September 2011, Hewitt & Simpson (2012) reported detecting 54 ecological trends consistent with increased sedimentation. Analyses on data to October 2013, detected only 27 of those trends, and 5 of those were only possible trends. Many long-term cycles (7-12 years) have been observed in species abundances in the Manukau Harbour Ecological Monitoring Programme, and cycles such as these would generally be detected as trends with less than ten years of data. Appendix 7.2 details the numbers of trends consistent with increased sedimentation reported in Hewitt & Simpson (2012) for each of the selected taxa and the two community variables, together with the number still detectable in the analysis of data to October 2013. Importantly, while a large number of trends were previously detected for the number of taxa, very few (<10 %) were detected with an additional two years of data.

Table Appendix 7-10: Past and present trends consistent with increased sedimentation.

	2014	% remaining	new trends
Capmud	11	55	5
#taxa	8	50	1
Anthopleura	1	0	1
Aonides	3	67	1
Austrovenus	3	67	0
Austrovenus small	-	-	1
Austrovenus medium	2	100	0
Austrovenus large	1	100	2
Colurostylis	6	17	0
Corophidae	1	0	0
Crabs	1	0	0
Macomona	2	0	0
Macomona medium	3	0	0
Macomona large	1	100	0
Nereididae	1	100	3
Paphies small	1	0	1
Paphies medium	-	-	1
Waitangi	5	80	1
Sediment mud content	2	50	0
Sediment very fine sand and mud	21	90	3
Percent organic matter	-	-	5

7.4 Health data

Table Appendix 7-11: Health index data for monitored sites from each estuary from October 2014 and 2015.

Estuary	Site	Year	BHMmetal	BHMmud	TBI
Whangateau	1	2014	-0.07	-0.07	0.39
	1	2015	-0.08	-0.08	0.48
	5	2014	-0.05	-0.04	0.56
	5	2015	-0.05	-0.03	0.53
	7	2014	-0.06	-0.06	0.64
	7	2015	-0.08	-0.06	0.69

Estuary	Site	Year	BHMmetal	BHMmud	TBI
Puhoi	1	2014	-0.18	-0.13	0.48
	1	2015	-0.15	-0.09	0.30
	4	2014	-0.16	-0.09	0.30
	4	2015	-0.17	-0.13	0.46
	9	2014	-0.03	0.03	0.46
	9	2015	-0.03	0.03	0.40
Waiwera	1	2014	-0.05	0.01	0.51
	1	2015	0.00	0.06	0.34
	3	2014	-0.14	-0.08	0.24
	3	2015	-0.16	-0.13	0.55
	8	2014	-0.15	-0.12	0.44
	8	2015	-0.17	-0.11	0.50
Orewa	1	2014	-0.22	-0.16	0.25
	1	2015	-0.17	-0.10	0.26
	4	2014	-0.18	-0.14	0.52
	4	2015	-0.21	-0.17	0.47
	8	2014	-0.12	-0.05	0.46
	8	2015	-0.10	-0.02	0.34
	1	2011	-0.18	-0.13	0.37
Okura	1	2014	-0.19	-0.14	0.52
	1	2015	-0.19	-0.12	0.45
	2	2014	-0.09	-0.01	0.68
	2	2015	-0.04	-0.01	0.48

Estuary	Site	Year	BHMmetal	BHMmud	TBI
	3	2014	-0.16	-0.08	0.58
	3	2015	-0.16	-0.12	0.51
	4	2014	-0.16	-0.13	0.70
	4	2015	-0.15	-0.12	0.78
	5	2014	-0.17	-0.10	0.60
	5	2015	-0.13	-0.10	0.50
	6	2014	-0.12	-0.10	0.79
	6	2015	-0.10	-0.09	0.70
	7	2014	-0.14	-0.12	0.65
	7	2015	-0.15	-0.12	0.52
	8	2014	-0.17	-0.11	0.54
	8	2015	-0.07	-0.02	0.47
	9	2014	-0.05	0.01	0.45
	9	2015	-0.01	0.02	0.42
	10	2014	-0.04	0.06	0.56
	10	2015	0.00	0.06	0.54
Mangemangeroa	3	2014	-0.11	-0.07	0.71
	3	2015	-0.11	-0.08	0.69
	6	2014	-0.07	0.01	0.54
	6	2015	0.00	0.05	0.50
	9	2014	-0.03	0.06	0.38
	9	2015	0.02	0.06	0.38
Turanga	4	2014	-0.03	0.05	0.35

Estuary	Site	Year	BHMmetal	BHMmud	TBI
	4	2015	-0.01	0.06	0.28
	7	2014	-0.10	-0.01	0.38
	7	2015	-0.09	-0.03	0.65
	8	2014	-0.01	0.07	0.27
	8	2015	0.02	0.09	0.70
Waikopua	1	2014	-0.11	-0.05	0.70
	1	2015	-0.12	-0.08	0.61
	3	2014	-0.10	-0.06	0.59
	3	2015	-0.09	-0.08	0.49
	9	2014	-0.03	0.03	0.55
	9	2015	0.02	0.06	0.26

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